CRANFIELD UNIVERSITY

THE CIM INSTITUTE

Ph.D. THESIS

Academic Year 1993-4

VIRGILIO A. CRUZ MACHADO

Quality based strategy: modelling for lean manufacturing

Supervisor: Professor Peter J. Sackett

January 1994

This thesis is submitted in partial fulfilment of the requirements
for the degree of Doctor in Philosophy

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ABSTRACT

The research develops and applies an integrated methodology for creating a Lean Manufacturing Environment in a traditional industry: the Portuguese Textile and Clothing Industry. This is achieved by developing a modelling tool using quality as a basis of performance assessment.

In the context of the textile industry specific research objectives were: to evaluate current and potential application of Lean Manufacturing; to determine current business performance assessment criteria; to determine current practice in formulation of quality policy and metrics, and their impact on the effectiveness of new production technologies and techniques; to develop an integrated methodology to link the variables identified as important for the creation of a Lean Manufacturing environment; to apply the methodology in selected industrial test sites; and to derive quality system specifications which allow the realisation of Lean Manufacturing.

The idea proposed in this thesis uses a quality approach to facilitate the application of Lean Manufacturing to the Textile and Clothing Industry. The author proposes a model for this evolution. The model developed includes objective variables (quality, productivity, delivery, cost, innovation, and time related elements), as well as subjective variables (flexibility, technological, and anthropocentric elements). It assesses the company performance from a Lean perspective, and not only from traditional Financial or Quality Assurance perspectives. The model development derived from applied research in 324 companies. A technique based on Data Envelopment Analysis was developed to analyse data from those companies. It assisted quantification of Lean Manufacturing assessment.

The research revealed that a particular set of companies, which have implemented quality assurance systems, are closer to achieving Lean Manufacturing objectives. This research project concludes with a proposal for new quality system requirements specifically designed to facilitate the adoption of Lean Manufacturing.

To my family

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PUBLICATIONS

The following work was published with respect to this research:

- "Assessment of technological performance in the mould making industry: the quality approach",
  Part I - *Molde Review*, Ano 5, n. 16, p.26-32, June 1992,
  Part II - *Molde Review*, Ano 5, n. 17, p.33-40, September 1992
- "Implementation of an integrated system in an industrial SME: a case study",
  Co-author with Pamies Teixeira,
  Proceedings of the 2nd International Conference on Automation Technology,
  Vol.2, p.313-318, Taiwan, July 1992
- "New techniques and technologies in a CIM environment",
  Competir Review, Ministry of Industry, Ano 3, n. 2, p.34-38, May-August 1992
- "Quality Systems performance in the Textile and Clothing Industry",
  1st EC Textile Congress, Oporto, December 1992
- "Performance modelling in CIM",
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  p.423-427, Manchester, March 1993
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  Quality Review (APQ), p.29-34, Ano XXIV, n.1, March 1993

Papers submitted:

- "A review of performance assessment methodologies in CIM organisations",
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- "Performance assessment of quality systems in the textile industry",
  Co-author with Peter Sackett
  International Journal of Operations and Production Management
- "Quality based strategy: Modelling for lean manufacturing",
  Co-author with Peter Sackett
  Total Quality Management

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NOTATION

ABC	Activity Based Costing
AMT	Advanced Manufacturing Technologies
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CATI	Computer Aided Testing and Inspection
CE	Concurrent Engineering
CIM	Computer Integrated Manufacturing
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
EC	European Community
FMEA	Failure Mode Effect Analysis
FMS	Flexible Manufacturing Systems
FTA	Fault Tolerance Analysis
JIT	Just-In-Time
MRP	Manufacturing Resources Planning
PEDIP	Programme for the Development of the Portuguese Industry
QAE	Quality Assurance / Anthropocentric Efficiency
QC	Quality Control Quality Circles
QCTE	Quality Assurance / Cycle Time Efficiency
QDLTE	Quality Assurance / Delivery Lead Time Efficiency
QFCE	Quality Assurance / Failure Costs Efficiency
QFD	Quality Function Deployment
QFE	Quality Assurance / Flexibility Efficiency
QGE	Quality Assurance / Technologies Efficiency
QIE	Quality Assurance / Innovation Efficiency
QLD	Quality Assurance / Lateness of Delivery Efficiency
QMRW	Quality Assurance / Materials Residence in Warehousing Efficiency
QMSE	Quality Assurance / Material Scrap Efficiency
QPE	Quality Assurance / Productivity Efficiency
QPTE	Quality Assurance / Production Techniques Efficiency
QRME	Quality Assurance / Raw Material in warehouse Efficiency
QSTE	Quality Assurance / Setup Time Efficiency
QTDE	Quality Assurance / Timeliness of Delivery Efficiency
QTIE	Quality Assurance / Time to Introduce new products Efficiency
QVAE	Quality Assurance / Value Added Efficiency
QWIP	Quality Assurance / Work-In-Process Efficiency
QWTE	Quality Assurance / Waste Time Efficiency
SE	Simultaneous Engineering
TQM	Total Quality Management
WIP	Work-In-Process
ZD	Zero Defects

1. INTRODUCTION

This chapter presents the aim of the research. It deals with the background to the project, and reasons for undertaking it.

1.1. Aim

The demands of the market have required new ways of working in industry, as well as in services. Industry is experiencing enormous changes in its basic philosophy [MAR93]:

From	To
Economy of scale	Economy of scopes
Optimal lot sizes	Flexibility
Large work-in-process	Lot size 1, set-up minimum
Safe-guarded by high inventories	Un-interrupted work-flow
	Just-in-time production
	Inter enterprise

The market demands more individual goods. This means increased innovation and flexibility of design, production and sales [FRI92]. This flexibility must be attained in an economic way. This is not a question of flexible automation (a technical concept), but of flexibility of business process. This environment requires the development of new strategies. The ultimate goal of a company is business system optimisation instead of the suboptimisation of individual functions of the company.

Optimisation can be achieved with a structured sequence of improvement projects. Feigenbaum [FEI88] suggests that improvement comes about through direct and continuous management leadership to institutionalise a strong and integrated quality system throughout all areas of organisation.

One of the main areas of research and development in total quality is the need to deal effectively with the upstream area of quality that is, development and engineering. Pressure is being put on quality management to provide the systematic foundation for this, so that clear and effective quality processes are themselves managed and systems engineered throughout the organisation with the same attention through which the product and service is managed, engineered, produced and sold.

This new situation requires that we analyse the performance and the potential of an organisation. Performance indicators have been used in the industry as standard references of the evolution of a company. These indicators are mainly based on economic and financial analysis. In addition, the use of quality assurance tools such as certification and standards for assessment of company performance is superficial. They are limited to whether or not a specific procedure is being applied. These tools do not allow exploration in depth of the performance of new technologies and production techniques that were or are being implemented. A company can have a quality system installed with the respective quality manual and procedures; the company can even be certified complying with ISO9000 or BS5750. It does not mean that the company is effectively using the new technology and techniques. If it does not have methodologies and optimisation techniques, documented and formalised in a systematic way to deal with the technology, we cannot say that this company has an adequate decision support system.

Consequently, it is necessary to take a critical look at the existing models for assessment of performance of quality systems. This should allow analysis in depth of the level of optimisation achieved and the effective domain of the new technologies and production techniques.

These technologies and techniques suggest the use of methodologies that we can recognise in the quality principles. However, this recognition has not been widely identified due to the lack of integration between the people that work and develop the technology and the people that work in the quality area.

The situation described applies in many industries. It is apparent in the Textile and Clothing Industry (TCI). The TCI is a traditional industry that is experiencing problems throughout Europe. In Portugal, it is one of the most important industrial sectors (see Annex 1).

1.2. Lean environment in traditional sectors

Traditional sectors, like the Textile and Clothing Industries, are facing crisis in all the European Community (EC) countries [IFO88, FOR90]. There are two main reasons for this situation: the fierce competition from non EC countries and the Quality of the products/services delivered to customers. These conclusions are supported by the European Commission in the report "The Cost of Non-Europe in the Textile Industry" [IFO88]. The large investment in advanced manufacturing technology does not appear to have given an adequate return. This may be due to factors such as a shortage of skills and expertise. Another reason is that the development and implementation of a Quality Policy in the textile industry is not well advanced. There are some misunderstandings about the meaning and the concepts of Quality Management and Quality Assurance. This suggests that these concepts must be reviewed to fit the culture of this particular Industry.

One solution is to increase companies' competitiveness via cost reduction and quality improvement, to keep the customer satisfied. This presupposes a better internal organisation. A better organisation is synonymous with a mean and Lean Manufacturing environment [STE92, WOM90]. This can be widely applied. However, in traditional industries it can bring more benefit. The drawback is that, because they are traditional, they frequently resist change, and it is difficult to implement such ideas.

1.3. Assessing performance

The situation described suggests that modelling for Lean Manufacturing in traditional sectors is a vital research strategy. Modelling performance for Lean Manufacturing implies a full understanding of all the factors involved in the manufacturing process.

In the 1980s many new concepts and techniques appeared. The new ideas were introduced under various labels which by now are familiar: "just-in-time", "zero defects", "total quality management", "flexible manufacturing systems", "quality function deployment", "design for manufacture", "group technology", "production cells", "team production work", and "computer integrated manufacturing", to name a few. The development of so many new ideas in a relatively short period of time raised new problems. Most of these ideas require radical changes in production organisation and systems [MCC90]. New technologies and production techniques demand new organisational systems. Trigg [TRI92] suggests that when levels of technology change increase, there are necessarily greater needs for organisational change. As a consequence, traditional ways of modelling and assessing performance are not useful in the new market environment and the development and control of new performance assessment tools is a powerful management advantage and enables a better utilisation of technology. It is a step forward in the optimisation process.

However, traditional accounting and management systems have been running for so many years that the change to include new features (specific for new production systems) must be carefully addressed. This research project brings some new light to a traditional industrial sector where the effects of the introduction of new advanced manufacturing technologies have not been well controlled.

1.4. Research

1.4.1. Domain

Advanced manufacturing methodologies tend to ignore traditional industries. This research is targeted directly at the application of modern techniques in a well established and traditional industry. The sector selected for this purpose is the Textile Industry. To provide focus this has been restricted, geographically, to the Portuguese textile industry[1]. The author has substantial experience in, and access to, this industry [MAC92, MAC93].

1.4.2. Justification

The crisis in this industry is not a technological crisis [WAL91]. The technology is quite well advanced and sophisticated. The literature and experience show that competitors (mainly from the Third World) have in general inferior technology and human skills, and training and education infrastructures in these countries are less advanced. This situation justifies this research work targetted to provide new insights into improving manufacturing performance in this industry. Modelling for Lean Manufacturing is my approach to contribute, as a researcher, to a better quality environment.

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[1]Recently, Porter studied the Portuguese industry and advised to re-invest in traditional sectors, namely in the Textile Industry [POR93].

1.4.3. Objectives

This research seeks to develop and apply an integrated methodology for creating a ***Lean Manufacturing Environment*** in a traditional industry: the textile industry. It was believed that this could be achieved by developing a modelling tool using quality as a basis of performance assessment.

In the context of the textile industry specific research objectives were:

- Evaluate current and potential application of Lean Manufacturing.
- Determine current business performance assessment criteria.
- Determine current practice in formulation of quality policy and metrics, and their impact on the effectiveness of new production technologies and techniques.
- Develop an integrated methodology to link the variables identified as important for the creation of a Lean Manufacturing environment.
- Apply the methodology in selected industrial test sites.
- Derive quality system specifications which allow the realisation of Lean Manufacturing.

1.4.4. Methodology

The objectives above implied an in-depth knowledge of the textile situation. Building on the author's existing knowledge and a literature review, the first phase included an evaluation and characterisation of the level of Organisation for Total Quality in the most representative textile companies. Questionnaires were sent to the universe of the TCI and data from 324 companies was collected and analysed. It provided a basis for the selection of 30 companies where technical and quality audits were carried out to assess their manufacturing and quality systems. Finally, all this data was analysed to provide vital input in modelling for Lean Manufacturing.

Alternative modelling strategies were examined. Focus on quality principles was maintained throughout.

The in-company work was based in the quality audit techniques to assess quality systems and the quality assurance standards were used as reference documents. Via auditing it was proposed to evaluate the input variables for the lean model. The approach was to use quality audits as the starting point to integrate the results of different audits. This procedure allowed to quantify global company performance based on the results of those audits.

During the project, a technique based on Data Envelopment Analysis was adapted to analyse data for the model development, avoiding the direct use of weighting variables. This technique allowed quantification of Lean Manufacturing assessment.

This methodology was tested in a representative set of Portuguese Textile and Clothing Industry. The results were used to formulate appropriate quality system specifications.

1.5. Structure

Chapter 1 describes the reasons for undertaking this work, the research objectives, and the methodology.

Chapter 2 reviews the most relevant literature. It presents the main objectives of Lean Manufacturing and discusses the need for a specific strategy to achieve them. The role of performance assessment systems is investigated, in particular, quality systems performance. An approach to performance assessment is presented.

Chapter 3 discusses the need for a quality based strategy in modelling performance for Lean Manufacturing. The model development is presented and the model variables are identified and analysed. The concept of optimal performance design in Lean Manufacturing is presented. An insight into model implementation issues is provided.

Chapter 4 presents main methodologies and techniques developed for the modelling process. It includes questionnaires and audits design, and the procedures used for selecting and weighting performance measures.

Chapter 5 presents the main results from the diagnosis questionnaires, audits and model application. It considers different scenarios for the model application.

Chapter 6 provides new quality system requirements for Lean Manufacturing, based on the model formulation and results from previous chapters. It addresses the need for new quality tools.

Conclusions, final recommendations and suggestions for further work are drawn in Chapter 7.

2. LITERATURE REVIEW

This chapter reviews the most relevant aspects addressed in the literature. It presents the objectives of Lean Manufacturing and discusses the need for a strategy. The role of performance assessment systems is investigated, in particular, quality systems performance. An approach to performance assessment in the textile and clothing industry is described.

2.1. Lean Manufacturing

2.1.1. Objectives

Traditional mass production is based on a rigid and extensive division of labour and a serial production flow [ELL92]. In garment manufacturing, assembly lines are used, providing material flows that are well defined, giving an appearance of rationality. During the last decade the traditional assembly line production has been strongly criticised [AGU80, SCH92a]. The theoretical high productivity possible in an assembly line is difficult to achieve in a systematic way [WOM90]. This is mainly due to the natural human variation in working pace, the sensitivity to disruptions, the difficulty of balancing the work operations, and the need for extensive inspection and adjustment of the objects assembled. In addition, products have become more complex and the number of product variants has increased [POR85, HIL91]. This has greatly increased the number of different components that have to be provisioned along the assembly line. This situation leads to space shortages along the line, material handling problems, difficulties in task balancing, an increase in complexity.

In traditional assembly line work, the work is fragmented and the individual's working pace is controlled by the movement of the assembly line. These working conditions have led to high levels of employee turnover and absenteeism, and have undermined process control and the sense of personal responsibility for product quality. Internationally, the trend has been to redefine assembly lines. Some common methods for improving an assembly line are quality circles, teamwork, just-in-time principles, product standardisation, etc [KUM91].

The expression *Lean Manufacturing* was coined by J. Krafcik [KRA88] in 1988 to refer to a production form incorporating the above improvements on traditional mass production. The notion of Lean Manufacturing covers a broad range of activities including product design, the purchase of parts, manufacturing processes, and marketing of products. Lean Manufacturing:

> "... is "lean" because it uses less of everything compared with mass production - half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product in half the time. Also, it requires keeping far less than half the needed inventory on site, results in many fewer defects, and produces a greater and ever growing variety of products [WOM90].

This implies that the main objectives of Lean Manufacturing are high productivity, high capital turnover and high product quality. Lean Manufacturing means short work cycles, standardised work methods, minimum number of employees, reduced inventory stocks, eliminated or reduced buffers and reduced floor space. Organisationally, workers belong to teams and mutual help and information sharing within and between the teams are encouraged, job rotation and the transfer of workers to new jobs are widespread practices, both formal and on-the-job training is extensive and the acquisition of multiple skills is rewarded. Figure 1 illustrates the advantages of Lean Manufacturing.

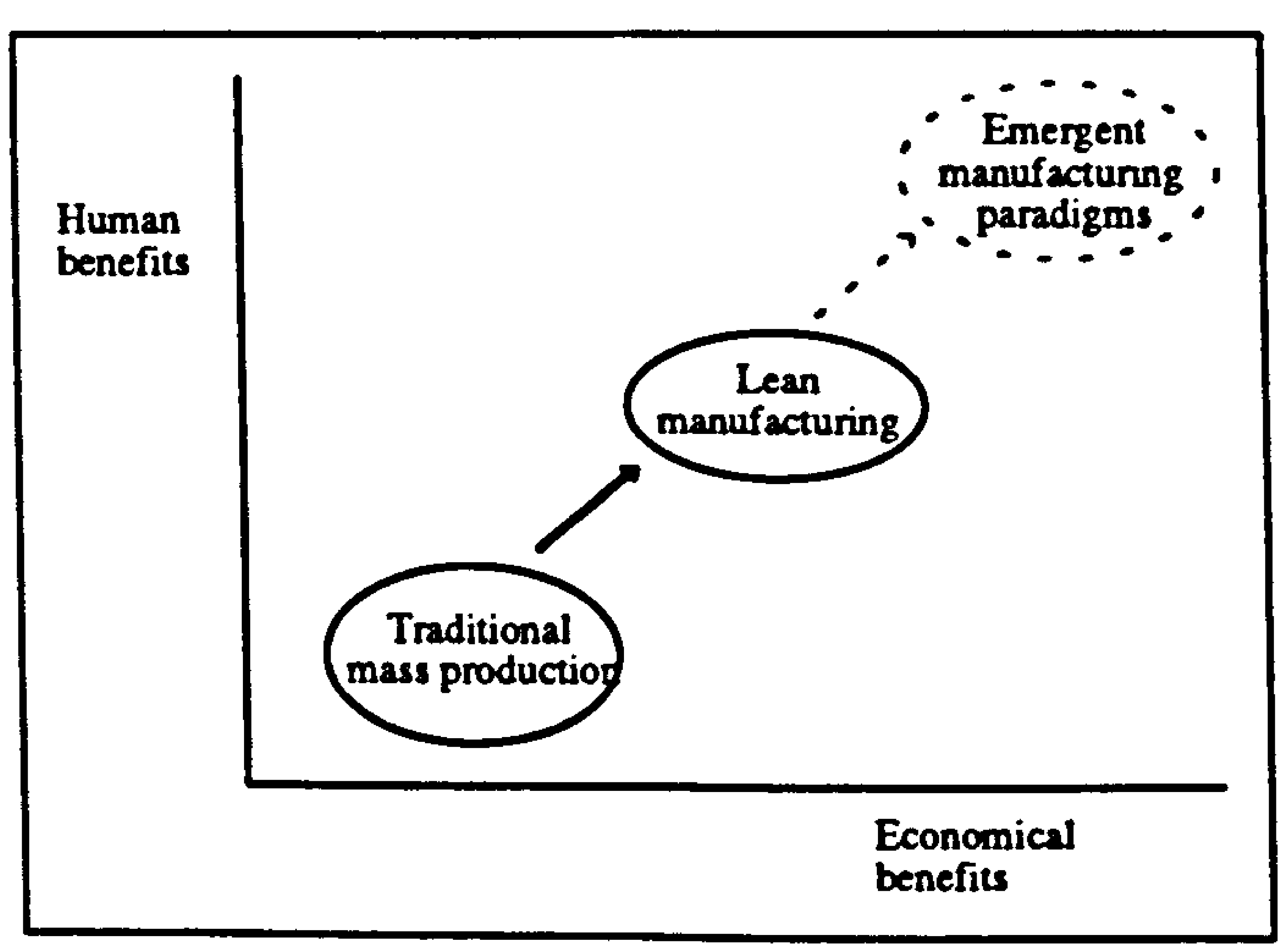

Figure 1 - Mass production vs. Lean Manufacturing

The development of Lean Manufacturing is moving to new emergent manufacturing paradigms [BOR93]. O'Neill and Sackett [ONE93] describe the concept of the Extended Enterprise. They emphasise product customisation to improve customer satisfaction. In Sweden, Ellegard [ELL92] suggested the concept of Reflective Production, to improve the human benefit. Traditional industries need to address Lean Manufacturing before progressing beyond it.

Important values in Lean Manufacturing are thoroughness, consistency and steady, incremental improvement with perfection as the ultimate goal. The problem-solving approach is to identify and eliminate the cause of the problem rather than to rely on a quick fix. Womack, Jones and Roos [WOM90] argue that the *truly* lean plant has two key organisational features:

- It transfers the maximum number of tasks and responsibilities to those workers actually adding value to the product on the line,
- It has in place a system for detecting defects that quickly traces every problem, once discovered, to its ultimate cause.

This means teamwork among line workers and a simple but comprehensive information system that makes it possible for everyone in the plant to respond quickly to problems and to understand the plant's overall situation. It is the dynamic work team that emerges as the heart of the lean factory.

Competitiveness requires that the products have one or more of the following advantages [NEW92]: low cost, high quality, good service, and value adding innovation. Product diversity and delivery time performance can be achieved by eliminating all non-value-adding activities, generally termed as waste. Anything other than the minimum amount of equipment, materials, space, information, people, and time essential to add value to the business is a non-value-adding activity. Lean Manufacturing is synonymous with waste elimination at all levels. These aspects are illustrated in Schonberger's world-class manufacturing model (Table 1).

Table 1 - Lean Manufacturing - World-Class Manufacturing

General:	• Know the next and final customer; know the competition • Continuous improvement in quality, cost, response time and flexibility
Design and organisation:	• Reduced number of components or operations, suppliers, and flow paths • Product and customer focused linkages of resources
Operations:	• Reduced time, distance, inventory, and space along the chain of customers • Reduced setup, changeover, get-ready, and start-up time • Operate at the customer's rate of use
Human resource : development	• Develop human resources through cross-training, and continual education, • Develop operator/team-owners of products, processes, and outcomes
Quality and problem solving:	• Make it easier to produce or provide the product without error • Record and retain quality, process, and problem solving
Accounting and control:	• Cut transactions and reporting • Control causes, not costs
Capacity:	• Improve resources and human work before thinking about new equipment • Automate incrementally when process variability cannot be reduced • Have plural instead of singular workstations for flow lines for each product family
Marketing:	• Market and sell the firm's capability and competence

(Adapted from [NEW92])

2.1.2. Strategy

In the late 1980s there was an increasing awareness of the need for manufacturing strategies. There is a lack of understanding about what constitutes a manufacturing strategy and the process by which strategies may be formed. Plats [PLA90] confirms that there is a need for a process which can assist both the formulation of manufacturing strategy, and the checking and updating of existing strategies.

Bowman [BOW90] defined strategy as, "the definition of the basic long term goals and the objectives of an enterprise, and the adoption of courses of action and the allocation of resources necessary for carrying out these goals". For some companies long term can be five or more years, and for others it can be only two years. Strategic decisions embrace:

- Corporate strategy: the determination of what business the corporation should be in,
- Business strategy: how to compete in the selected businesses,
- Functional strategy: how the function can contribute to the competitive advantage of the business.

Manufacturing has been considered the functional level strategy. Swamidass [SWA90] suggests: "manufacturing strategy is viewed as the effective use of manufacturing strengths as a competitive weapon for the achievement of business and corporate goals". A manufacturing strategy defines how manufacturing will assist in the achievement of the business objectives through the provision of appropriate structural items (buildings, plant and equipment, etc.), and the appropriate infrastructure (people, organisation, control policies, etc.) to ensure that operations are effective.

For many years manufacturing was not seen as a contributor to business strategy. It was conventionally managed from the bottom-up. In 1969 Skinner [SKI85] suggested a top down approach to manufacturing claiming that only when basic manufacturing policies have been defined can the detailed system design and engineering be undertaken. These ideas have formed the foundation from which current thinking in manufacturing strategy has developed. Wheelwright [WHE84] developed a conceptual framework enabling the assessment of manufacturing within the corporate strategy, Figure 2. This framework decomposed manufacturing strategy into decision areas (process, capacity, plans, vertical integration, infrastructure) and made the goals of manufacturing explicit in terms of performance criteria (efficiency, dependability, quality, flexibility). Wheelwright considered that this framework enabled the bridging of the gap between corporate strategy and manufacturing strategy which exists if manufacturing management are simply given a statement of corporate objectives. This framework with modifications has formed the basis for much of the subsequent work in manufacturing strategy [HAY84, HAS87, SLA91, HIL92].

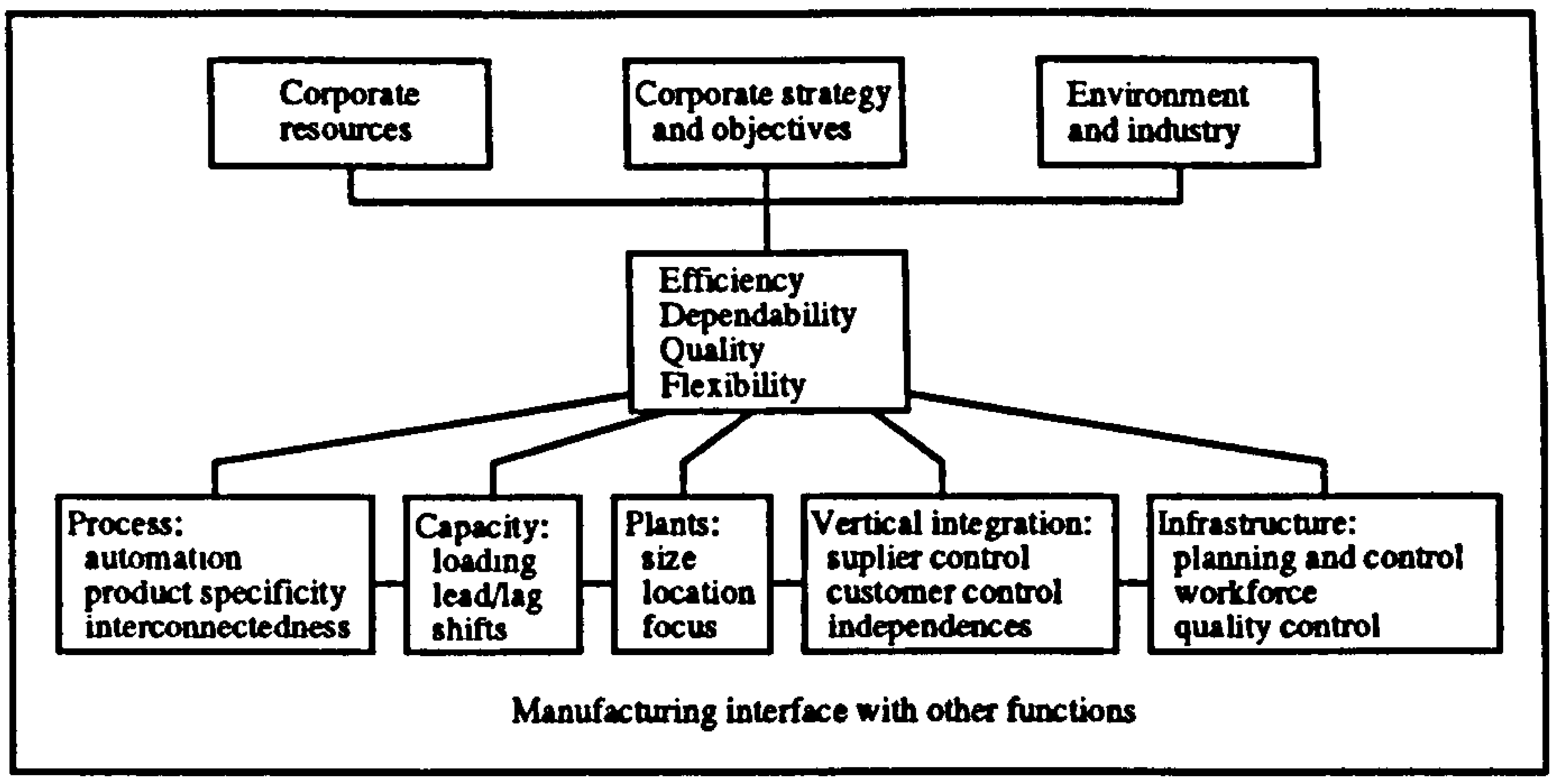

Figure 2 - Manufacturing strategy and operating decisions [WHE84]

Traditionally, improvements to manufacturing processes have been based mainly in costs reduction analysis, with little attention paid to, non-costs factors such as quality and delivery performance. Manufacturing systems have evolved which do not satisfactorily contribute to the competitive position of the company. Many companies did not define manufacturing strategies to support the overall business strategies. The literature is reviewed by Kleindorfer & Partovi [KLE90], Plats [PLA90], Scharlaken [SCH92b] and New [NEW92]. Plats discusses the need of a manufacturing audit approach as a process for the formulation of a manufacturing strategy. Kleindorfer & Partovi present a prescriptive methodology relating marketing and manufacturing strategy to choice of technology. They developed a model for evaluating alternative technologies. Scharlaken [SCH92b] presents a manufacturing technology planning to maximise their investments in new technologies.

A study of 184 Swedish companies [TUN92] showed that companies that have a manufacturing strategy are significantly more profitable, emphasise quality programmes and other preventive actions to a greater extent, and achieve higher business performance than those without one. Tunälv identified four manufacturing objectives: flexibility, quality, delivery and cost. These objectives are supposed to guide decisions and establish plans and policies within the manufacturing structure and infrastructure to align the manufacturing capabilities with the business strategy.

The literature on manufacturing strategy is near uniform in its division of the manufacturing resources into subcategories. Wheelwright [WHE84] suggested eight major types of decision categories:

- Capacity
- Facilities
- Vertical integration
- Production technologies and processes
- Quality and product assurance
- Production planning and materials control
- Organisation

These decisions areas were considered to be of long term importance in the manufacturing function and should be designed to be internally consistent and guided by policies to support the manufacturing objectives and therefore the business strategy.

The technological and business environment has changed rapidly and substantially. Categories such as vertical integration should be substituted by overall integration (vertical plus horizontal integration). Flexibility, time and anthropocentric issues are other categories that must be considered in the process of designing a strategy. It is impossible to define a manufacturing strategy without taking into account the business objectives. This implies including management and engineering people [HIL92]. Defining a strategy for Lean Manufacturing is vital. It should be objective, clear, simple and easy to follow. The traditional approach to the solution of management problems has been to create complex systems and mathematical solutions. This approach has contributed to the development of highly sophisticated but poorly performing companies - reliant upon specialists and technicians - whose production personnel are alienated and unproductive [BET92].

Japanese companies have demonstrated the enormous value of simplicity and participation [CUS88]. Rather than approaching a complex problem by devising a complex solution, simplify the problem so that the resulting solution is clear to everyone involved. Traditional management methods of performance measurement, in traditional companies, has not realised the benefits of improvement projects [KAY91]. The solution to these issues could be to devise more complex accounting that fully reflect the complexity of modern industrial life. My approach is to focus on the fundamental issues and develop performance measurement methods that address these issues in a way that is clear and straightforward. The development of such a model is a step forward in designing a strategy for Lean Manufacturing.

2.2. Systems performance

2.2.1. Purposes

Performance is the efficiency with which inputs are converted into outputs. Historically performance has been measured by individual ratios, such as return on capital or output per employee, and more recently value added ratios. The primary purposes of performance assessment have been reviewed [KAP86, McN88, KAP90, MAS91, BLE92]:

- To compare efficiency in relation: to current budget; to competitors; or similar companies; to prior results over time; to other units within the same company;
- To provide a basis for corporate planning;
- To provide the means to monitor the progress towards the objectives defined in the manufacturing strategy;
- To determine standards for reward purposes;
- To provide the basic information for capital appraisal, namely, the output for very low levels of aggregation;
- To report financial health of the company to outside interests, such as shareholders and creditors;
- To provide information for decision making, for example, to assist managers in pricing company's products or in make/buy analysis;
- For other management purposes, such as collective bargaining with trade unions, assessing the effects of prospective governmental restrictions, etc.

2.2.2. Traditional

The techniques of management accounting were developed over a period from the late nineteenth century until the 1920's and 1930's. During this time theoretical and practical methods of management accounting became established. These accounting techniques became the accepted method of measuring the performance of a manufacturing plant [JOH87].

The measures of financial performance have been, in the past, the most important source of information in assessing managers in performance evaluation and decision making and control. Maskell [MAS91] goes further saying that the way that companies have traditionally measured production performance has been determined by the needs of the cost accounting system. Although there have been dramatic changes in manufacturing techniques and technologies over the last twenty years, management accounting has stayed the same. Maskell identified five main shortcomings of traditional management accounting: lack of relevance; cost distortion; inflexibility; impediment to progress in world class manufacturing; subjection to the needs of financial accounting. Kaplan [KAP90] found that many US companies at the leading edge of JIT and CIM developments are using cost accounting systems developed seventy five years ago. Kaplan identified three major problems with traditional cost systems: they distort product costs; they do not produce the key non-financial data required for effective and efficient operations; the data they produce reflect external reporting requirements far more than they do the reality of the new manufacturing environment.

Andersin [AND92] criticises current cost accounting systems: systems that are based on distributing overhead costs based on direct labour cost are not suitable for an automated and integrated environment. Factors other than labour based cost drivers and activities must be used as vehicles for product costing. Automated and integrated manufacturing is getting more like a continuous process so it is necessary to know the cost of the process instead of the product. Process cost accounting should be an almost real time system providing production management with information needed for current decision making.

Ferreira and Lin [FER91] have summarised the implications of the changing manufacturing environment [FRI92] on management accounting. These innovations have allowed companies to enjoy economies of scope and to diversify their product lines to meet unique consumer needs. The new manufacturing technologies have also created a demand for increased co-ordination among various organisational units and for significant investments in production scheduling. These innovations shift the focus away from large production volumes necessary to absorb fixed overhead to a new emphasis on marketing efforts, engineering and product design. These changes have stressed some of the weaknesses of conventional accounting, and alternative costing systems, such as target costing, activity-based costing and throughput accounting, have recently attracted commercial interest.

Target Costing is used especially in Japan instead of standard costing. It is suitable for the motivation of personnel but does not give information about real product costs. Activity Based Costing (ABC) is probably suitable for an integrated environment. In ABC, the costs incurred by activities are obtained, and allocated to products using cost drivers. These reflect the characteristics of products or production processes which lead the activity to cause cost. Its application is demanding in terms of information processing, time and effort, and few well researched case studies of these applications in companies are yet available [AND92]. Throughput accounting derived from the OPT principles and is similar in concept to the contribution of limiting factor (a variant of marginal costing, where only variable costs are charged to a product). Throughput accounting pursues maximisation of profit by manufacturing the product mix which makes best use (return) of critical resources. All costs, with the exception of direct materials, are assumed to be fixed. The overheads recovery is made according to the use of the key resources made by a product.

Azzone *et al* [AZZ91] suggest a framework for designing a performance measurement system which is consistent with time-based principles and can support managers both in strategic and in operating decisions. The framework takes into account different ways through which a company can use time to create a competitive advantage and considers the main activities that are critical for achieving such results. This framework includes three parts: part one deals with the impact of time and responsiveness on value (it analyses how time to market can change the competitive position of a company); part two shifts the focus from the company as a whole to its activities, to point out which of them are critical to improve time to market; part three is concerned with the presentation of a taxonomy of the information needed by managers in their co-ordination function. As the emphasis is on reducing time to market, the model only includes a limited number of company areas and performance indicators: research and development (engineering time); operations (throughput time) and; sales and marketing (order processing lead time).

In a survey about the implementation of Just-in-time in the UK and US industry, Billesbach [BIL91] found that the use of performance measures in a JIT environment is not well developed. Slow moving material in a traditional manufacturing system results in natural audit points for measurement of activity and performance, which also serves as an input measure against which productivity may be measured. Under JIT, information flows between accounting, production and material functions are radically altered. Costs are no longer accumulated by individual jobs or work stations but instead are collected at a departmental level. Information collection becomes difficult when a product is continuously moving through the system. This situation confirms the impact of manufacturing developments on the need for a new performance assessment model to meet the challenge of not only JIT, but also other new techniques and technologies.

Kaplan [KAP86] proposed that accounting researchers need to develop measures of manufacturing performance that assess the key factors affecting a company's profitability in today's rapidly changing marketplace. Accounting systems that work in conjunction with a company's manufacturing policy, and not in opposition to the production environment must be devised. Improved measures of quality, inventory performance, productivity, flexibility and innovation will be required so that managers can focus on achieving long term success and not be burdened by the current emphasis on short term profitability.

The whole field of performance measurement has to be revised to serve management in a lean environment. It is envisioned that present performance measurement systems will be replaced by new systems involving a customised network of indicators aimed at decreasing non-value-added factors, waste, disturbances and increasing emphasis on key factors of competitive advantage. Suitable indicators could be for example lead times, setup times, number of product variants, amount of work-in-process, quality, number of customer complaints, quality of customer service.

2.2.3. Business objectives

The consensus (in the literature) is that accounting measures alone are insufficient for the competitive environment of the 90's. Changes in the manufacturing environment, cost structure and information processing capabilities stress the need for a balanced combination of measures of a financial and non-financial nature.

Performance should measure the overall achievements of a company, including how it uses available resources, how it progresses towards objectives defined by the business strategy and how it is positioned in comparison to its competitors. Although the position relative to main competitors in terms of market share, order winning and qualifying criteria, price and delivery lead time, etc. is well known within companies, this is not usually regarded as a relevant dimension within a broader perspective of a performance measurement system. The key to successful performance measurement is to recognise that if measures of performance are to reflect the systematic nature of the units to which they relate, they must be arranged in a systematic way; they must be integrated one with the other and all in turn be related to the goal of the unit. Attempts to set up such a system must be preceded by a clear definition of the objectives of the business unit concerned. It is important to choose a small number of pertinent performance measures that enable the company managers to assess progress constantly. If a company measures its performance and reports the results, people will be motivated to improve. Appropriately selected performance measures, derived from the business objectives, show to all people the priorities that are important to the company.

2.2.4. Technology and production techniques

New technologies and production techniques potentially enable companies to become more competitive in the market [PLO91]. Although the strategic potential of Advanced Manufacturing Technologies (AMT) seems enormous, introducing and implementing these technologies can be a costly and risky venture [HAR92]. It can create operating problems and have repercussions on human resources, quality of work life, labour relations, materials management, reject rates, and equipment downtime. Borden [BOR91] reviewed the literature on performance measurement and product costing in the AMT environment. He concluded that the decision to invest in AMT is most often not accompanied by an investment in the company's accounting system. The likely outcome of such a situation is that performance measures become misleading and reported product costs drift away from "true" product costs.

Companies that have installed AMT often find that their investment has not been viable. Primrose [PRI91] concluded that the problem is related with the incorrect application of investment appraisal and costing principles. Burnes and Weekes [BUR89] state that for some companies the results of introducing advanced manufacturing technology have been disappointing. They argue that if AMT is to be successful, its use must be part of an overall, company-wide strategy to improve competitiveness rather than a one-off response to localised problems. Danila [DAN91] developed a model to support the strategic planning process activities. It uses analytical and intuitive modelling approaches, and incorporates quantitative and qualitative data. However, this model has some limitations concerned with the use of difficult to assess subjective techniques.

Kutay and Finger [KUT90] developed a formal methodology to enable companies to assess the economic benefits of new production technologies, particularly, the integrated design and manufacturing systems. This methodology integrates investments in new production technologies into the business strategy of a company.

Berry [BER92a] presented a framework to determine manufacturing planning and control system requirements that reflect differences in manufacturing strategy and process technology in a business. He discussed examples of companies which have developed a good fit between their manufacturing planning and control systems and their manufacturing strategy in terms of the framework presented.

Partovi [PAR91] presented a methodology relating manufacturing strategy to choice of technology. He proposed a method for technology evaluation in manufacturing organisations. The model presented by Partovi is in the form of a hierarchy that includes the forces driving competition, their components, activities in the value chain, and corresponding technologies in those activities (Figure 3).

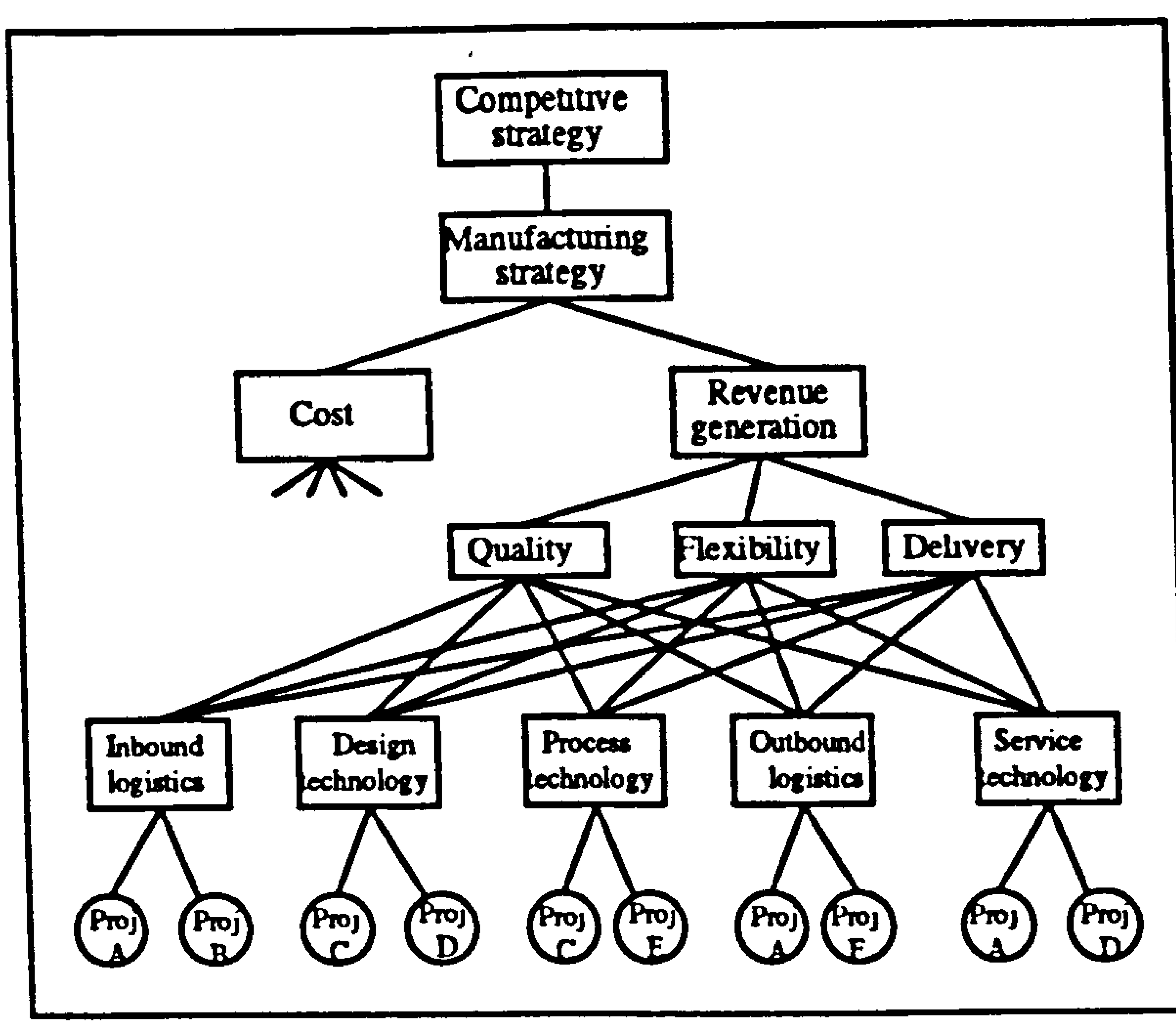

Figure 3 - Partovi hierarchical Model

Meredith [MER87] presented some of the major difficulties in implementing the automated factory. He concluded that the adoption and implementation of advanced manufacturing technologies is not a technical problem, it is a managerial problem. In this field, Senker and Simmonds [SEN91] studied how relationships between technology and working conditions change over time. They concluded that failure to adopt appropriate strategies for innovation, lack of appropriate technical skills, reluctance to change work organisation and failure to adopt appropriate organisation structures can all inhibit the effective use of technology.

Porter [POR85] points out that technological change can affect competition not only through its impact on core technologies but also in support activities such as procurement, office technology or design. Technology can affect a company's competitive advantage if it has a significant role in determining relative costs or product differentiation. Technological change can quicken the pace of new product introduction and the most effective use of technology can only be secured by means of coherent strategies with such objectives in mind.

Rayner [RAY91b] shares the opinion that in spite of an ever increasing number of implementations of advanced manufacturing technology, few achieve great success. He estimates that over 70% of attempted implementations of MRP II could be judged unsuccessful. The systems themselves might have been inappropriate for the company's particular operating environment. The design of the project, and its subsequent implementation, might have been poorly conceived or managed. Standards of education and training might have been insufficient. Rayner considers two main factors outweigh all others:

- the need for internal cultural changes
- lack of explicit performance standards to measure and monitor the implementation

For Rayner TQM can form an integral component in the introduction of AMT, as it overcomes the problems outlined above in a systematic way. He argues that TQM is an enabler of change and change cannot be effected merely by the introduction of new technology. It is intimately concerned with people. It acknowledges the fact that, while technology might provide the capability, people provide the ideas and the impetus for the improvement of business performance.

Bennet *et al.* [BEN87], looked at the issue of performance evaluation by examining the problems that appeared to accompany the adoption of AMT. Bennet looked at four specific types of factory automation: numerical control (NC) machines, computer aided design/computer aided manufacturing (CAD/CAM), flexible manufacturing systems (FMS) and material handling systems. The authors found it difficult to quantify the benefits of NC machines and to separate the cash flows for different machines. Also, it was difficult to evaluate machine utilisation using statistics designed to evaluate labour. For CAD/CAM, Bennet have suggested a set of possible criteria for evaluation: number of drawings, designs, NC programs and proposals developed; time required to develop designs; frequency of engineering change orders; time required to perform design analysis. In looking at flexible manufacturing systems, they proposed measurements such as machine and system utilisation, productivity of the FMS, actual vs. planned throughput time per unit of product, manufacturing flexibility, quality, levels of work-in-process, raw materials, and finished goods inventory.

Finally, for performance measurement of automated storage/retrieval systems, a number of operating statistics are recommended, including the measurement of systems operating time, computer operating time, computer picks per worker hour and an acceptable inventory accuracy percentage. In summary, Bennet *et al* feel that accountants need to work more closely with manufacturing and engineering to develop new performance measures.

In performance measurement in AMT environments, McNair *et al.* [McN88] point out that present emphasis on cost measurement will be replaced by a total performance measurement system that monitors flexibility, dependability, quality and cost. McNair have identified a wide array of performance measurement areas, such as: design for manufacturability, zero defects, minimisation of raw in-process inventory, zero lead-time, minimisation of process time, optimisation of production, production linearity, zero set-up time, zero finished goods inventory, management cost structure, minimisation of total life cycle cost.

Technology choice is fundamental to the planning processes in manufacturing. Traditionally, the ranking and choice of projects for technological modernisation in a manufacturing environment relied on capital budgeting, techniques such as payback, internal rate of return and present value [SWI85, NOB89, PAR91]. These techniques have been extensively used in industry because of their ease of application; rational, tactical financial assumptions; and treatment of the time value of money. These models have been criticised as they do not include intangible benefits such as improved quality, increased flexibility and decreased delivery time. Some authors claim that capital budgeting techniques are the greatest barrier to the implementation of new techniques and technologies [KAP86, JOH87].

Most research in this area has been descriptive in nature [CHU91, PAR91]. However some authors have proposed models related to choice of technology. Swamidass [SWA90] proposes a set of indices of cost, quality, and flexibility which measures the deterioration of installed technologies in terms of these factors. Swamidass concluded that unlike manufacturing technologies of the past, whose impact was limited to the shop floor, new manufacturing technologies have a pervasive impact on the organisation which extends to every aspect of the organisation. Consequently, justifying these technologies is more complex. Purely financial approaches are too limiting. Justifying investments in automated technologies is a complex decision due to the number of attributes and their interactions to be included in the investment analysis. The task of including non-financial qualitative aspects of manufacturing performance is becoming a vital issue.

Randhawa and West [RAN92] present a classification scheme for CIM justification techniques based on the nature of the decision environment, and describe the more commonly used techniques. Table 2 compares two literature reviews on techniques used in technology justification. Most of the literature reviewed did not consider non-financial issues in the evaluation of technological issues.

Table 2 -Review of techniques used in justifying automated technologies

Randhawa Classification	Swamidass Classification
• Payback • Net Present Value; Internal Rate of Return • Linear and Integer Programming • Scoring Models • Analytical Hierarchy Process • Utility Theory • Goal Programming • Decision Trees • Markov Analysis • Simulation • Expert Systems • Optimistic-Pessimistic Models • Strategic Approaches	• Discounted Cash Flow • Scoring Methods • Costs and Benefits • Risk Analysis • Computer Enhanced Approaches • Strategic Value of Flexibility

The systems used to control manufacturing also require new financial and operating measures of performance. These measures should be consistent with the criteria used in the initial investment evaluation. That is, performance measures should reflect the strategic goals of the firm, such as the requirements for long-term survival and/or growth. Current management accounting systems are sometimes inadequate because of their short-term emphasis and focus on the allocation of fixed costs. Some of the problems and issues include increasing overhead rates, shrinking base of direct labour over which to allocate costs, and increasing fixed costs and decreasing variable costs [KAP90].

Ghosh and Wabalickis [GHO91] share the opinion that traditional procedures alone are not appropriate for justifying advanced manufacturing systems. It is necessary to consider the benefits of new technology in manufacturing systems since financial return is dependent on many factors outside manufacturing. They used an analytic hierarchy process to combine and synthesise tangible and intangible benefits of advanced technology.

The extent to which new technologies can support business goals in productivity, quality and flexibility is an especially important issue for manufacturing firms. Problems have arisen in developing performance measures and evaluation criteria which reflect the full range of costs and benefits associated with these technologies. Some authors argue that managerial policies and attitudes, and not the shortcomings of the equipment or manufacturing processes, are the major impediments to implementation [LIB90, BUS92].

Models for justification of manufacturing systems are abundant in published literature. The papers reviewed have provided important considerations in justification of complex systems. In general, they neglect performance objectives not directly linked to technological performance. The differences between these papers and the approach in this work is the intention to integrate technological issues with performance objectives.

2.2.5. Quality systems

A basic performance objective is Quality. However, much of the available literature on quality performance assessment is written from the point of view of "conventional" engineering manufacture. This opinion is shared by Rogerson [ROG88].

The first use of scientific assessment techniques to try to improve the efficiency of organisations were developed in the 1930s. The first was in the area of product quality assessment, beginning with Shewhart's work on statistical quality control (SQC). The second technique for assessing an organisation's performance focused on financial analysis. The third technique approached assessment through the actual structures, processes, relationships, and elements that make up an organisation. In this approach, men like Elton Mayo and Maslow explored the dynamics of participation, group involvement, and work environment. Recently, Spaulding [SPA89] used this last technique to develop a model to assess an organisation based on five key dimensions of quality: customer focus, total involvement, measurement, systematic support, and continuous improvement.

Assessment of quality systems has become a common practice as a safeguard for product quality. It was originated in the aerospace and military industries and later it was spread to energy and major infrastructures, where guaranteed results in terms of quality are a customer requirement. Now Quality assessment has been adopted in sectors where it is a necessary market qualifier.

This type of quality assessment is usually concerned only with the area of the company system that deals with product quality assurance. Some researchers [INM90, CON91] think that this situation is focused on the ability to "comply with the specification" rather than on "customer satisfaction", and does not embrace the principle of "continuous improvement". Conti [CON91] considers that traditional external and third party assessment schemes no longer meet the needs of total quality organisations. He recommends the use of "self-assessment" as a method for measuring organisational excellence and continuous improvement. For this purpose he developed a reference model whose components are the results, processes and the quality system itself. The goal of well structured companies is to reach "total quality" through performance measurement and continuous improvement [PAN91, NEE89].

Golomski [GOL90] considers that there are three sets of measurements about quality: quality measures; productivity measures; and, performance measures. Quality measures are usually about products, processes and people (ex: sampling plans, measures of capability, quality costs, complaint rate, etc.). Productivity measures are based on the relation "output of intended product/inputs". Finally, performance measures are viewed as the combination of all possible measures (profits, units of production, safety measures, quality measures , productivity measures). Most measures of quality are for lack of conformance rather than satisfaction. Operational measures of satisfaction are considered an important area of research.

Bossink *et al* [BOS92] developed a total quality management model that describes the basic elements of the concept of TQM. Based on this model they developed a quality-diagnostical instrument to establish actual TQM situation in an organisation. The elements of the model are: totality, line-staff relationship, technological perspective, cultural implantation, management commitment, upstream emphasis, market-in approach and integration. To turn these elements operational for practical use within an organisation Bossink used 63 concepts (ex: zero defects), methods (ex: quality circles) and techniques (ex: Pareto analysis). Determining the presence or absence of these concepts, methods and techniques supporting the quality management of an organisation, provides a means of determining the degree and implementation of the TQM concept.

Jennings [JEN89] modelled a set of mechanisms by which organisations could continuously improve production and support processes. The components of the model include: organisational structure and task design, human resource management systems characteristics, communication and information systems design, and organisational leadership behaviour and tactics. The model hypothesises that these variables have their impact on the institutionalisation of incremental innovation through the mediating mechanisms of empowerment, learning and goal setting. The application of process related technology was proposed as a moderating influence, minimising or amplifying the effects of the prior casual variables. The model proposes an integrated combination of mechanisms that would allow organisations to institutionalise an ability of incremental innovation to improve product and process quality. As a model for continuous improvement it does not allow one to measure its results and performance.

Lawton [LAW89] presented a process for obtaining, quantifying and acting upon information regarding three main factors: the objective performance of the service or manufactured product; the perception of the product and related subjective experiences and; the outcome or desired results achieved by use of the product. This is a model for creating a customer-centred culture in a service environment. It addresses five major elements (process, structure, tools, measures and strategy) and has six key steps (defining service support, differentiating customers, defining expectation, measuring quality, describing the process and managing performance). As measures of performance the model includes only three sets of measures: productivity (volume and timeliness), quality (yield and accuracy) and profitability (unit cost and unit value).

Babar [BAB92] discusses limitations of contemporary methods in use for the control of quality in services. He models a system and provides a quality management framework. The model uses information gathered through a chain of customers input and feedback in ensuring competitiveness through continuous improvement. The system is supposed to allow management to initiate processes that enhance their ability to shape and control quality at all levels. This model does not allow to measure performance.

Kievit [KIE92] describes a simplified method for assessing how well the quality system is being implemented. It has a form of a progress matrix which uses only two A4 pages, and it is more suitable for service organisations. This methodology gives a subjective analysis of the quality system performance but it does not provide an objective quantification.

Duncalf and Dale [DUN88] developed an analytical method for assessing a manufacturing organisation's approach to quality management. This method uses a quality-related decision-making approach with impact on product quality. The application of the method is supposed to provide managers with information on the reality of their quality assurance activities.

Some researchers [KEL91, WAC89] consider that the current literature does not give a comprehensive theoretical model to evaluate quality improvement projects economically. Wacker [WAC89] argues that because of the lack of theoretical models and the complexity of quality improvement systems, integrative efforts co-ordinating marketing and production have been largely ineffective in the strategies of firms; they have not been subject to traditional cost-benefit analysis. Consequently, it is not possible to conclude about relative importance for continually improving the process. Wacker developed an integrative strategic quality management theory and a cost-benefit model to aid managers in evaluating quality improvement programmes. This is an interesting type of assessment, but it is limited to specific quality improvement projects.

Another researcher, Kumru [KUM84] developed an evaluation system in a two-stage operation which measures the quality performance of factories according to their performance scores and improvement tendencies. In a first stage the evaluation is based on a simple scoring technique, by which overall percentage and initial performance scores are attained. In a second stage, after a period of improvements, the initial performance scores are revised using a quantitative technique and final performance evaluation is completed. As measures of performance Kumru considered three components: scrappage percentage (total scrap/total production); returns percentage (total returns/total sales); corporate quality auditing defective percentage (total defectives/total inspected units).

Popplewell [POP90] presents also a list of examples of quality indicators, organised by business function. These indicators form an essential component of a total quality programme, and they are used to measure the performance of the system.

The literature identifies a large set of indicators of performance. Some of them are: manufacturing lead time, direct labour profitability, work in progress turnover, vendor lead time, indirect productivity, inventory turnover, inventory accuracy, absenteeism, outgoing quality, unit manufacturing cost, unit material cost, overhead cost, on-time deliveries, incoming quality, labour productivity, material yield, forecast accuracy, unit labour costs.

A group of researchers [KAN84] developed the two-way model of quality. In constructing their model, they considered two aspects of quality: an objective aspect involving the presence or absence of a quality attribute (its fulfilment or unfulfilment), and a subjective aspect involving the user's resulting sense of satisfaction or dissatisfaction. This is reflected in the following way:

1. How would the user feel if the attribute in question were present or fulfilled?
2. How would the user feel if it were absent or unfulfilled?

According to its presence or absence, each attribute is classified into: attractive, one-dimensional, must-be, indifferent and reverse.

For Gryna [GRY91], an important starting point for strategic quality management is setting quality goals. This implies that it is important to assess the company's current status on quality. He identified three main areas of assessment: quality relative to competition, cost of poor quality and organisational culture on quality. These three areas of assessment can identify threats to sales income, opportunities for cost reduction, and obstacles to a new approach to quality.

A key part of assessment is opinions from the market place. This implies: identification of key quality attributes, relative importance of key attributes, company status relative to the competitors, effect of competitive differences on users and search for changes in goods or services to create a competitive advantage. What the customer thinks of the product quality applies not only to external customers, but also to internal customers. Gryna relates examples from manufacturing industries and services (ex: marketing research by a quality department and by an engineering department to learn how the manufacturing internal customers view the services provided to them).

Another part of assessment is the cost of poor quality. The methodology for estimating these costs has been well developed. This methodology should not be restricted to manufacturing. It should embrace all processes in the company: product development, marketing, purchasing, billing, customer service.

The third area of assessment is understanding the opinions, perceptions, beliefs, traditions, and practices related to quality for the organisation - the company culture. This is considered to be based on: management's attitude on quality vs. production quotas; the quality of input to and output from departments; the clarity of specifications, work instructions, and personal roles in quality; and, obstacles to solving major problems. However, to draw conclusions about a company's culture means collecting information from a large and representative group of employees. These three types of assessment provide important but incomplete snapshots of a company's quality status.

Another form of assessment appraises the performance and results of the quality management system. The Malcolm Baldrige National Quality Award and the Deming Prize have been used as a criteria for this assessment [EDO91, RUS91]. Another set of criteria being used are the quality assurance standards ISO9000/EN29000 [BRE91, HER90, DAG89] and BS5750 [ILL88, PEA90]. An assessment with these criteria can show how well an organisation's quality system is conforming to the basic quality functions defined in the standards.

Quality auditing, with standards as reference documents, is a management tool that must be applied with belief and integrity throughout the company [ART89, LEE91]. Internal quality audits can be applicable to small and large industrial and service industries [RAY91a]. It is an essential measure of how the business is performing. Tilley [TIL84] found that the companies' lack of attention to the subject of internal audits is one of the major deficiencies of the quality systems of those companies.

Kistler [KIS89] points out the importance of the human element in the assessment of productivity. He developed a mathematical model to relate human productivity to several aspects: equipment, motivation, direction, communication, success and self image. He argues that the productivity, performance effectiveness or achievements of humans depends on their equipment, skills and attitudes, and so the performance of a company must take into account the human performance and the performance of individuals.

This contrasts with the results of a survey of 250 mid-sized companies carried out by Thornton [THO91]. Sixty nine per cent of all companies considered productivity as a problem. Forty percent cited investment in new plant or equipment as the single most important step to improve quality. In contrast, only twenty four per cent said that investing in people was number one answer to the productivity problem. Another twenty percent of the companies cited quality or process improvement as their major weapon against poor productivity.

Measurement of quality is less advanced in service industries and in the support services (finance, personnel, research) found in manufacturing companies. Early [EAR91] discusses the measurement of service quality. He identifies three types of measurements: some are "leading" indicators of quality performance (ex: the time it takes to get a new service to market); others are "coincident", like process failure rates;

and, others are "lagging" (ex: customer complaints). However, he advises special attention to leading indicators: cost of poor quality, economic data about the firm, complaints and comments, direct customer surveys, discrete attributes, continuous variables and time, accuracy, precision and usefulness of information. The development of appropriate measures to assess (service) quality start with the customer needs [KOG92, VOS92]. Then it is necessary to look at the processes performed by the organisation, identify how they relate to the needs of the internal and external customers, and determine the appropriate measures for each component of the total organisation. The number of customer complains is often regarded as an external quality indicator, although an increase in the number of complaints may indicate better communication with customers rather than deteriorating product or service quality.

Schvaneveldt [SCH91a] made an investigation of service quality to explore how consumers evaluate the quality of services. He considered a framework for consumer evaluation of service quality. Using a survey data of consumer expectations regarding quality improvement he derived broad evaluation factors which underlie consumer expectations for service quality attributes. These attributes were categorised according to their level of fulfilment and were compared with the consumer's sense of satisfaction or dissatisfaction. The result of this was considered an input for quality planning and assurance activities.

Another tool used in the assessment of company performance is the evaluation of quality costs. The cost of quality is a business analysis tool, but some authors think it is not always the best tool to use in every instance [VLA89]. There are some difficulties of measuring the costs of quality, namely: the identification and visibility of all quality costs, the information available at the point of control and the risk of assessment.

Dowd [DOW88] reports that in many companies the cost management systems fail to support the business: product costs provide misleading information to decision makers; performance measures are inappropriate for factory management, investment appraisal techniques are inadequate, the overall cost management effort is unfocused as effort is applied to the measurement of costs rather than identifying the causes of costs and eliminating them, and accounting systems are over complicated.

Plunkett and Dale [PLU86] carried out detailed case studies of the collection and use of quality related costs in manufacturing industry. The feeling from the research is that companies are beginning to amass and use quality cost-data but in a limited way, using mainly scrap and rework costs. Quality cost reporting is still not accepted as one of the normal activities in reporting of quality performance. Abed [ABE87] report another study attempting to identify and collect quality-related costs in manufacturing organisations in the textile industry. They found that none of the companies studied had a formal system for collection and use of quality costs; the collection and analysis of such costs was carried out on an "ad hoc" basis.

The collection and analysis of quality costs has provided an objective means of determining the cost effectiveness of the quality function. Gibson [GIB91] reports that measuring these costs is difficult because they are distributed over a number of departments and they fall outside established company accounting practices.

Table 3 summarises developments in modelling quality as cultural values.

Table 3 - Quality as Cultural Values

Model	Two stage	Attribute satisfaction	Decision making	Mathematical model of human productivity	Strategic	Triangulate reference	Business function	Service quality	Goal oriented
Metrics	First stage Initial quality performance as Scrap % Production % Returns % Production Total defects Total inspected units Time lapse Second Stage same measures	Satisfaction/ /Dis-satisfaction Against 1 - Fulfilled product attribute 2 - Unfulfilled As: Attractive One-dimen-sional Must-be Indifferent Reverse	Impact of decision making on quality	Mathematical evaluation of: Equipment Motivation Direction Communi-cation Success Self-image	Benefit of strategic cost quality in specific projects	1 - Quality as process people and products 2 - Productivity output 3 - Performance as combined cumulative measure	Functional measures of system	Satisfaction/ /Dis-satisfaction as fulfilment of consumer expectation Evaluation as cost of quality	Quality relative to competition Cost of poor quality Organisation quality/ market opinion Internal and external customers
Proponent	M. Kumru	N. Kano N. Seraku S. Tsuji	F. Duncalf B. Dale	E. Kistler	J. Wacker	B. Gold	Popplewelll	Schvanevel T. Enkawa M. Miyaka	F. Gryna
Date	1984	1984	1988	1989	1990	1990	1990	1990	1991

(From [MAR93])

2.2.6. CIM

Lean Manufacturing requires the integration of the company's activities in a Computer Integrated Manufacturing (CIM) perspective. By definition an integrated company behaves as a whole. Attributes like *co-ordinated, orderly, consistent, predictable* can be applied to such a company. A second way of defining company integration describes the internal structure of an integrated company, often attributing the use of information technologies to being integrated. Such technologies include company wide information networks, common databases, and interfaced computer systems. Other structural features contributing to integration are the use of crossfunctional teams, simultaneous engineering.

CIM involves linking together all the business functions in a manufacturing organisation to form an efficient unit [LEO91]. It is not confined to the shop floor activities, but embraces the total business. CIM systems supply the communication links to bring together the numerous computer tools into a cohesive network, which in turn provides prompt, up-to-date information for management to make decisions and control. Information technology plays a key role both in manufacturing automation and integration. It is one of the major building blocks of the integrated manufacturing enterprise. Information and its effective communication are also important resources upon which the survival of an organisation depends. In addition, the manufacturing information system plays a key role in raising productivity, profitability, and competitiveness, culminating in significant benefits. Enterprise data and especially technical data are vital corporate resources.

For measuring the degree of enterprise integration Andersin [AND92] considered an infrastructure based on: information systems, economic, people, organisational, and product and operations components. This model for measuring degree of enterprise integration is seen as a three stage concept: there must be an integrated infrastructure containing all the enabling factors for integration, if the infrastructure is successfully implemented, an integrated behaviour should be observable in the enterprise, finally, some results will emerge. Every stage of the concept can happen only if the previous stage has been achieved.

Foong and Hoang [FOO91] analysed the links between business strategies and manufacturing technologies. They developed a mathematical model to look into ways of linking business strategies to the given technologies, so that an implementation path for CIM can be direct and standardised.

Technology alone is not the answer when pursuing enterprise integration. The critical success factors are much more complicated and interdependent and they are based on a combination of advanced technologies with modern business practices and methods. The discussion of these matters has lead to a definition of the elements of enterprise integration that should be assessed for measuring the degree of integration [CIE91]: culture, management and organisation, technology, enterprise process improvements, and process for change.

2.2.7. Enterprise

Successful enterprises must respond efficiently to the changing competitive environment. Their problems are more complicated than before because many changes are occurring not only simultaneously but also more rapidly than in the past. These changes occur in all sectors of manufacturing and they include [BRA88]: more complex products, higher quality, increased product liability, more customised products, shorter product life cycle, increased global competition, and more demanding customers [SAC93].

Gunn [GUN87] has addressed the objectives of manufacturing strategy that must be met if a company is to become a world class manufacturer. These objectives are: shorter product development lead times, shorter manufacturing lead times, higher quality, more inventory turns, more flexibility in the production processes, better customer service, less waste, and higher return on assets. Gunn states that for most companies three missing elements prevent them from becoming a world-class manufacturer. These three missing elements are vision, senior management leadership, and a process for translating the vision into reality. Along with these missing elements world-class manufacturing also requires a commitment to quality, an educated and motivated work force, proven technology, and effective planning.

De Toni *et al* [TON92] suggest a conceptual model for operations that can be utilised in identifying the most significant opportunities and decisions to obtain competitive advantages in global industries. The model considers the following elements: competitive advantages, the performance of the operating and the four phases of the so-called operation value chain: design, purchasing, production and distribution. The study of the implications on production strategy deriving from globalisation is carried out using three groups of strategic decision categories: organisation and management, management systems, technologies. The crossing of the three groups of strategic decision categories and the four operation phases identifies a matrix with twelve areas of opportunities and decisions for realisation of global-type strategies.

Japanese manufacturers consider quality, dependability, cost, and flexibility as priorities which must be addressed sequentially over time [STA90a, TUN92]. To offer dependability (as a competitive means) a company needs to qualify at least for a minimum level of quality. To be cost efficient it has to qualify for a minimum level of quality and dependability. To become flexible, it has to have a minimum level of quality, dependability and cost efficiency. Wheelwright [WHE84] describes the Japanese approach in a similar way, where the focus on quality is a prerequisite for gaining flexibility and dependability, which in turn will help to reduce the overall costs.

Table 4 shows different manufacturing competitive priorities and measures of performance used in Europe, Japan and USA.

Table 4 - Manufacturer's competitive priorities

Manufacturer's Competitive Priorities		
Europe	**Japan**	**USA**
Conformance quality	Reliable products	Conformance quality
Dependable delivery	Dependable delivery	Dependable delivery
Reliable products	Rapid design changes	Reliable products
High performance	Conformance quality	High performance
Fast delivery	Product customisation	Price competition
Measures of Performance		
Outgoing quality	Manufacturing lead times	Incoming quality
Unit manufacturing cost	Direct labour profitability	Inventory accuracy
Unit material cost	Work in progress turnover	Direct labour productivity
Overhead cost	Incoming quality	Manufacturing lead times
On-time deliveries	Vendor lead times	Vendor lead times
Incoming quality	Indirect productivity	Work in progress turnover
Labour productivity	Materials yield	Materials yield
Materials yield	Inventory turnover	Outgoing quality
Forecast accuracy	Inventory accuracy	Indirect productivity
Unit labour costs	Absenteeism	Raw materials inventory

(from [INS91])

About company performance there are in the literature many contributions from different authors. Table 5 shows a resumé of indicators used by main authors.

Table 5 - Main indicators of company performance

Author	Indicators
De Tony [TON92]	• Total cost; Quality; Timeliness of delivery; Time to introduce new products; Dependability (product quality and delivery time); Flexibility (product mix and capacity)
Ferdows [FER86]	• Quality; Dependability; Cost-efficiency; Flexibility
Hill [HIL92]	• Variable and fixed costs; Quality; Delivery time and dependability; Flexibility (in product specifications and production volumes)
Neely [NEE92]	• Quality; Time; Cost; Flexibility
Schroeder [SCH90b]	• Manufacturing cost; Quality (expressed as quality cost or customer satisfaction); Inventory turnover; Customer service; Cycle time; Time to introduce new products; Time to change capacity
Ward [WAR90]	• Costs; Delivery performance (dependability and speed); Quality; Flexibility (product mix and volume); Innovativeness
Wheelwright [WHE84]	• Cost; Product performance; Dependability; Flexibility; Innovativeness

2.2.8. Experiences

Table 6 shows a resumé of main characteristics of some studies found in the literature.

Table 6 - Some experiences in assessment studies

Study	Characteristics
Aguren and Edgren [AGU80]	A synthesis of case studies to examine organisational innovation in a variety of technologies in over 20 manufacturing plants, with the organisational emphasis on product focused forms.
Allen [ALL91]	A survey of 183 UK textile companies revealed that the implementation of documented quality systems was not well advanced. The findings show the absence of quality policies, lack of attention to quality training, and generally poor quality systems.
Bartezzaghi [BAR92]	Give results of a survey on the application of the JIT approach in ITALY, based on a sample of 173 industrial companies.
Bennett *et al.* [BEN87]	Case studies in seven American firms with NC, CAD/CAM, FMS, and AMH.
Betcherman *et al.* [BET90]	Nine case studies in Canada that combine innovation in AMT in a range of technologies with best practices in human resource management.
Coulson-Thomas [THO91]	A survey revealed that most European companies are focusing their attention on customer satisfaction.
Groves and Hamblin [GRO89]	A survey in the UK clothing manufacture revealed a lack of effectiveness of advanced manufacturing technology.
Howard [HOW91]	A survey of 100 leading companies in UK has shown that the concepts of TQM are recognised and endorsed by a minority of chairmen.
Inman [INM90]	In a survey of 106 firms that responded a questionnaire regarding the certification of their suppliers, it was found that 87% answered positively. This implies that quality certification of suppliers is a prevalent practice in JIT implementation.
Krafcik and McDuffie [KRA89]	Statistical analysis of interviews and quantitative data from 52 automobile assembly plants on five continents with a range of high and low robot utilisation.
Lockyer [LOC82, LOC84]	A survey on the practice of quality control in 240 UK manufacturing companies, revealed that industry makes low use of SPC techniques. The major barrier preventing companies from introducing SPC was identified as being lack of knowledge and awareness.
Long [LON91]	A survey reveal that small companies are not aware of the fundamental concepts of a quality system, and quality assurance. The main motivation for introducing a quality system which meets the requirements of ISO9000 is customer pressure.
Scott [SCO90]	A survey to managers in several countries shows that Japanese companies are superior in delivery speed. An overview of the relative industrial strengths of each country provided a discussion about manufacturing strategy.
Shaw [SHA91]	A survey of 673 Scottish manufacturing companies showed that senior management put strong emphasis on price competitiveness, product quality, delivery, some aspects of marketing and selective usage of planning, control and appraisal methods.
Sohal [SOH92]	A survey of Australian companies with a known commitment to quality, showed main general practices, human resource issues, quality control practices and quality programmes evaluation.
Swamidass and Newell [SWA87]	Statistical analysis based in interviews with corporate and manufacturing executives in 35 US firms engaged in small batch production.
Thomas [THO92]	This survey confirms that quality is considered number one for most CEOs. However, it is suggested that quality is but one of a number of changes that are occurring within organisations. The focus of quality is shifting to attitudes, values and perspective, and the creation of quality networks embracing customers, suppliers and business partners.

2.3. The textile and clothing industry

2.3.1. Technology

The textile and clothing industry (TCI) is a traditional industry. However it has come a long way from the "seamstress hunched over her work table making a custom garment at the rapid rate of 36 hand stitches per minute" [ALB89], to the operators sewing one process on one machine among large quantities of work-in-progress, to the sewing operator who stands while operating two to three different automatic or semi-automatic machines during one day at a group workstation. As in many industrial sectors, a major advance in production has been achieved through the development of machinery controlled by micro-processors and programmed by computers. New technology has facilitated the economic production of shorter runs, and this in turn has meant a greater variation in styles. The size of orders and type of garments produced today make a great deal of difference as to how a company can profitably make quality clothing. A staple manufacturer or one which produces high volume with low variety in the clothing, often at a low price, usually has the highly automated sewing operations with large work-in-progress. The high style manufacturer with low volume and high variety in garments would be concerned about fast throughput and flexible manufacturing.

In some segments of the clothing industry, such as men's dress shirts and blue jeans, machine automation has progressed substantially, while for the industry as whole, significant effort has been and is being made in plant layout, worker attitude, internal management systems and communication systems with suppliers and retailers.

In Portugal, apparel manufacturing has been primarily based in small companies with less than 100 employees producing limited types of garments. They produce fashionable garments, but are vulnerable to a single poor season. Because of their size, medium and large companies have greater chances to survive, but lack quick response. Today, there are larger companies due to consolidations. In some of these companies state-of-art advances are being applied due to companies' long term planning and ability to make large capital investments. These investments cover areas such as automation, CIM, CAD, CAM, FMS, cellular manufacturing, management systems and quality systems.

2.3.2. Automation

Automation and mechanisation have been largely applied to TCI. The main reasons for this situation include deskilling the craft aspect of the production process to reduce operator training time, increase productivity, eliminate waste, improve quality standards, and achieve greater consistency. All of this leads to reduced costs. Computers and microprocessors play an essential part in providing the speed, flexibility and linkages for automation.

2.3.3. Computer aided design

Computer aided design (CAD) systems include the capabilities to produce realistic pictures of various garments and options, alter pattern pieces for design features, size grade patterns, and make markers. Designs can be sketched on the screen or photographs can be inputted. These designs can quickly be changed according to specific customer requirements in terms of garment design, fabric design, texture and colour. Further, fabric design can either be created on the screen or inputted via scanners, with the option to change the colours. The resulting fabric design can then be wrapped around the figure to give a realistic look of the sketch [BER87]. This use of CAD allows to view the product before samples of the garment are made, thus saving time and expense. Sketched designs can be printed in catalogues.

Computerised programmes based on MTM (method time measurement) can quickly project synthetic values to determine realistic garment costs from a sketch. This results in better and faster communication between manufacturers and customers.

The use of a CAD system allows greater precision and accuracy which results in higher quality garments and fewer rejects [FIN89]. Other important characteristics of CAD systems are size grading and marker making. Marker making via the computer assures greater accuracy in the cutting, as pattern pieces are not forgotten and placements are true to the warp of the fabric. Computer marker making results in greater efficiency in fabric utilisation. It has been reported that a CAD system can cut six weeks from the production cycle [BER87].

2.3.4. Computer aided manufacturing

Manufacturing techniques aided by computers and microprocessors include the spreading and cutting of fabric and the assembling of the fabric pieces. Automation has been achieved with sewing and other machines and with the way the fabric moves through the factory. Electronically controlled spreaders are able to select different rolls of fabrics, spread different lengths of fabric for each ply, adjust the spreading speed and direction, and spread fabric face to face or face up. All of this can be accomplished with better tension control and better end and edge alignment than when manually, giving greater fabric utilisation and less waste [STE88]. Fabric inspection is an important quality function to prevent using inadequate fabric in garment pieces. Textile defect scanners or fault detection systems are used to detect flaws and digitise such into a machine.

Computerised cutting is also well advanced in the clothing industry. Knives are used to cut high and low fabric plys while lasers cut low and single fabric plys. Great accuracy is achieved from automated cutting due to the compression of the fabric layers, preventing shifting during the cutting process, and the precision in the placement and movement of the knife or laser. This precision helps the sewing machine operators to realise significant productivity improvements. However, due mainly to their high cost and large size these machines have only been introduced into large companies.

Automation of sewing machines is well developed. Computer controls that can be programmed include needle positioning, back tacking, thread clipping or trimming, foot positioning, stitch condensing and adding fullness. Sensors may be added to verify part position, thread breaks, skipped stitches, and fabric edge. These enhancements assist the operator in being more efficient thereby increasing productivity. The quality of the garment is also improved [FIN89]. However, the area where new technology has had least effect overall in recent years is in making-up, most especially in the knitwear and clothing sector. Making-up of garments remains a very labour intensive process.

2.3.5. Manufacturing systems

New, more flexible and faster ways of physically moving the fabric through the plants have been developed. The concepts of flexible manufacturing systems and cellular systems can be well applied to this industry. The unit production system of Figure 4 moves all the fabric pieces for one garment on a single hanger through the factory. The system is computer controlled and an overhead track guides the hangers to various workstations. A computer is used to balance the line by routing garments to sewing operators with high performance and low inventory [WAL89].

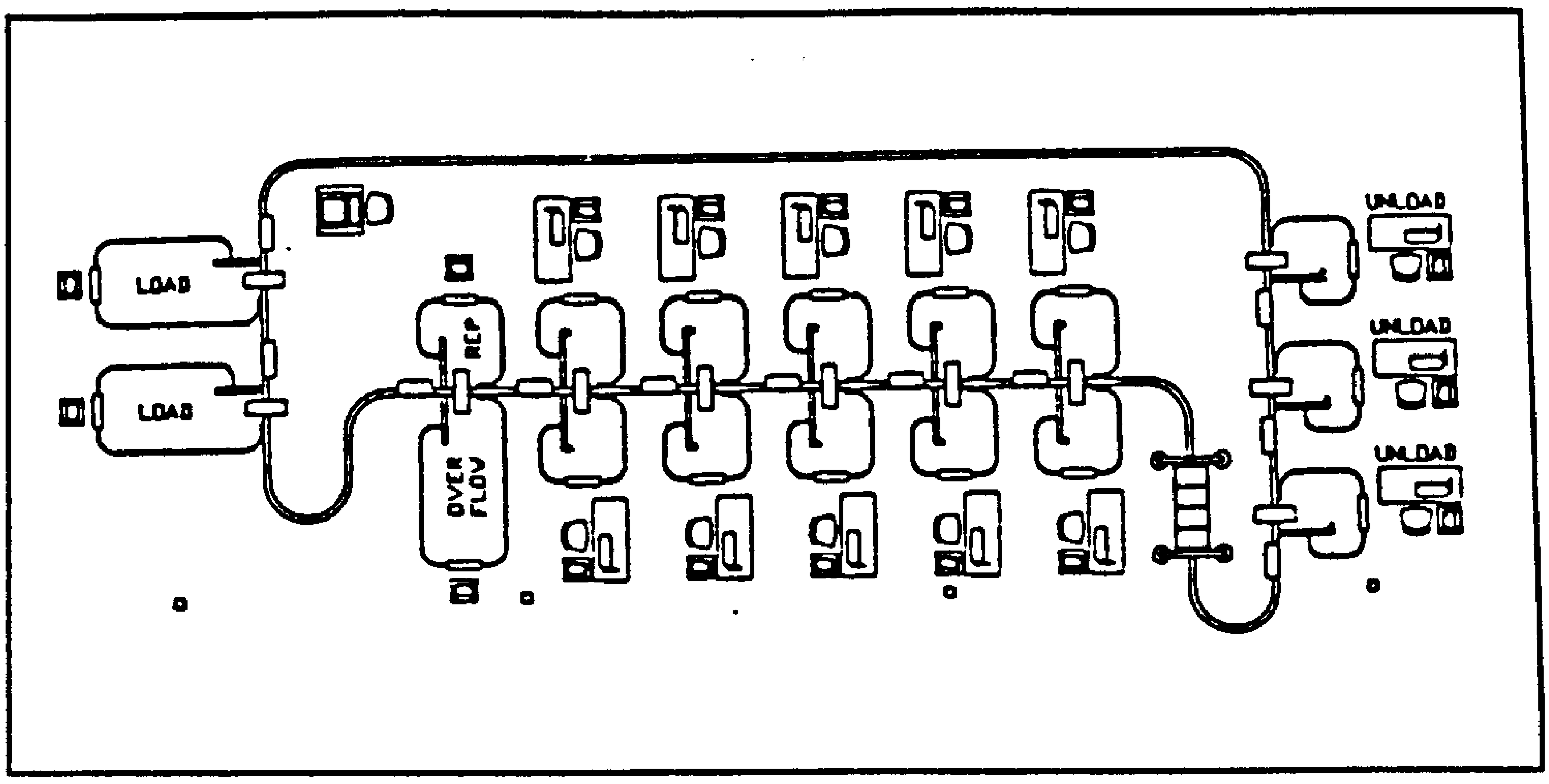

Figure 4 - Manufacturing system

Another system for moving fabric quickly through the factory is the cellular system (also called modular manufacturing or Toyota Sewing System) [ABE88]. The plant layout includes smaller grouping of machines in a U-shape to complete parts of a garment or a total garment, Figure 5. The close proximity of the machines facilitates movement of fabric pieces directly to the next operation, reducing the work-in-progress. In this system the number of operators is less than the number of machines. Each operator is trained to run two or three machines and moves from machine to machine to balance the line as necessary. To aid movement, the operators run the machines standing up. Cellular manufacturing requires team work to keep the line balanced or fabric pieces moving through smoothly. Each person needs to produce quality work or the whole team suffers the consequences of reworking the piece. To accommodate some garments, machines in the cell are changed rather than trying to fit various garments into the production line.

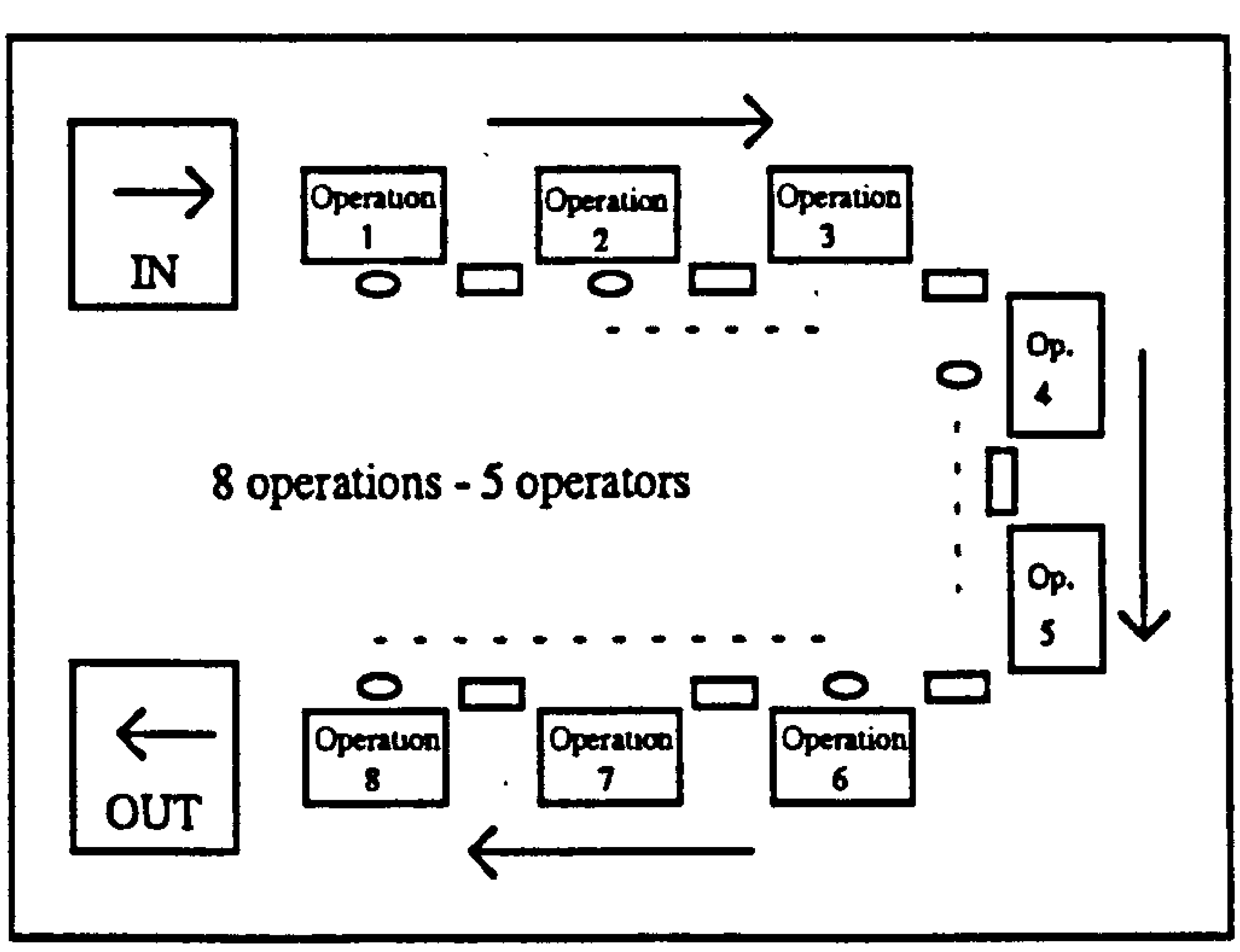

Figure 5 - Cellular manufacturing

Flexibility via cellular manufacturing is important to remain responsive in the market. Achieving high production and low costs may put a company out of business if it cannot be flexible or respond quickly to a new direction. Flexible manufacturing includes the ability to quickly produce quality products in the quantities needed and in time.

2.3.6. Management systems

Management systems are well developed in the clothing industry. Computer programs available for in-house use include MRP II, garment costing, cut-order planning, piece rate, MTM, and inventory and production control. These systems help manufacturers control functions such as styling, forecasting, distributing, work-in-process, inventory, securing raw materials, and scheduling. Bar coding is also used as an adequate tool for tracking the goods and work.

2.4. Summary

The literature reviewed in this Chapter identifies and clarifies Lean Manufacturing objectives. The achievement of these objectives is still under development for most advanced industries, namely the automobile industry. No references to Lean Manufacturing applied to the traditional textile industry were found. This led to a deeper literature research on two directions: on systems performance to get acquainted with current models and methodologies, and the textile industry itself. The purpose was to identify if existing models could be used in modelling for Lean Manufacturing in the textile industry. This review covered: technology and production techniques, quality systems, and enterprise performance. It was found that current methodologies for assessing systems performance are developed in an individual basis, depending on the specific background of its creator. For instance, although quality has been recognised as an important and even vital issue, none of the performance assessment systems seems to use it as its hard core. The quality tools and standards are just used to assess the companies quality systems. The literature reviewed does not give a comprehensive and integrated approach to global systems performance assessment.

3. THE MODEL

This chapter provides a framework for performance modelling. It discusses the need for a quality based strategy in modelling performance for Lean Manufacturing. The model development is presented and the model variables are identified and analysed. The concept of optimal performance design in Lean Manufacturing is presented. An insight into model implementation issues is provided.

3.1. Performance modelling

To assess how well a system is performing, a set of qualitative and quantitative criteria, or measures of performance, needs to be used. It should be noted that any assessment of performance is based on an estimate of capabilities, and this is limited by the knowledge and experience of the people involved. Estimation is a very delicate task. It involves assumptions concerning future capabilities, as well as consideration of past results and historical data. That is why, in an overall assessment, there is as much numerical comparison as subjective judgement. Subjective judgements must be well supported. Part of this research was related with the transformation of subjective into objective and quantified values. For instance, in the life cycle of a new manufacturing system, decision making is involved at various stages of planning, design, and operation. The role of performance modelling is to aid this decision making.

During the operational phase of a manufacturing system, performance modelling can help in making decisions related to finding the best routes in the event of breakdowns, predicting the effect of adding or withdrawing resources and parts, obtaining optimal schedules in the event of machines failures or sudden changes in part mix or demands, and in avoiding unstable situations, such as deadlocks. Performance modelling can also be used to answer basic design issues such as push versus pull production, shared resources versus distributed resources, the effect of flexibility, etc.. Generic performance measures include [MEY90, KAY91]: manufacturing lead time, work-in-process, throughput, machine utilisation, capacity, flexibility, performability, and quality. Using performance modelling, one can compute these measures of performance and use it in decision making and process improvement.

Performance modelling embraces not only technological aspects but also other objective and subjective aspects of the company. In this research Quality plays the underlying bedrock of the model developed for achieving Lean Manufacturing.

3.2. A quality based strategy for Lean Manufacturing

3.2.1. Historical perspective

A systematic approach to quality management can be defined [FEI91], Table 7. During the QI and QA phases the emphasis is on a technical perspective, Quality is considered to be an entity to be attained by technical means. In the TQC phase attention is centred on a cultural and structural perspective. The required quality has to be attained collectively, according to the relevant specifications and requirements. The subject of attention in realisation of quality is the organisation as a whole. In the TQM phase attention is paid to the maintenance, improvement and innovation of the products produced by the organisation and to the processes and organisation by means of which this is realised. Table 8 summarises these perspectives.

Table 7 - Characteristics of different phases in quality management

Phase	Characteristics
QI - Quality Inspection	Final inspection Upstream inspection with feedback (at the end of this phase)
QA - Quality Assurance	Use of statistical analysis Control of manufacturing processes Conformance to specs and procedures Solution to technical problems
TQC - Total Quality Control	Extension of statistical techniques Mutual harmonisation and co-ordination of all production processes Continuous improvement of products and processes
TQM - Total Quality Management	Continuous improvement of the culture of the organisation Mutual harmonisation and co-ordination of all processes Solution of technical and organisational problems

Table 8 - Perspectives of quality management phases

	Technological perspective	Cultural and structural perspective	Maintenance, improvement and innovative perspective
QI	Attention to the technological perspective: quality is considered to be a technical matter	Manufacturing: personnel are workers, have no voice Staff: personnel are thinkers, have much influence	At the end of this QI-phase: Maintenance in the manufacturing area Innovation is a separate activity
QA	The same as QI	Manufacturing is the centre of attention: manufacturing conform to specs and procs Staff: reduced influence	Maintenance in the manufacturing area Innovation is a separate activity
TQC	Attention to the technological and utilitarian perspective Emphasis lies still on the technological perspective	The organisation is the centre of attention: everyone must work according to specs, procedures and requirements Staff: continuing reduction of influence; plays more and more an advisory role	Maintenance and improvement of products and processes Innovation is a separate activity
TQM	Attention to the technological and utilitarian perspective Emphasis lies on the utilitarian perspective	The organisation is the centre of attention: habitual improvement; management is the supportive and stimulating factor	Maintenance and improvement of products, processes and organisation Integration of maintenance improvement and innovation

(Adapted from [FEI91])

3.2.2. Total quality management

> "TQM is concerned with moving the focus of control from outside the individual to within; the objective being to make everyone accountable for their own performance, and to get them committed to attaining quality in a highly motivated fashion. The assumptions a director or manager must make in order to move in this direction are simply that people do not need to be coerced to perform well, and that people want to achieve, accomplish, influence activity and challenge their abilities". Oakland [OAK89]

Fisher [FIS92] outlines seven key principles of TQM:

1. is a *management philosophy*
2. seeks *continuous improvement* in all processes, products, and services
3. requires the understanding of *variation*
4. emphasises the *importance of measurement*
5. requires the understanding of the *role of the customer* (and the supplier)
6. emphasises the *involvement of employees at all levels*
7. recognises that *management plays the key role*

Other authors like Shores [SHO92] and Nader [NAD89] report that at least, five management functions must be continuously improved to ensure that the business is using its resources efficiently and is achieving the highest levels of customer satisfaction. These five functions are also associated with Japanese TQM models, to elements in the Malcolm Baldridge Quality Award criteria and others:

- Management commitment,
- Leadership,
- Customer focus,
- Total participation,
- Systematic analysis.

Management commitment and *leadership* means that managers are responsible for providing direction and encouragement to the business [NAD89]. A *customer focus* keeps the business aware of the changes taking place in its environment and provides the knowledge needed to change the product or service. *Total participation* means that managers are responsible for synthesising all of the different processes and people in the business into a cohesive system focused on a common set of goals. *Systematic analysis* means that managers must also analyse variation detected in the business and in the environment and provide consistent responses and improvement. These five management functions can be viewed as a total quality management system. For Shores [SHO92] total quality management is the process by which business brings together resources (people, material, information and equipment) and orchestrates them to create products and services that have recognised value to the customer.

I see TQM in two forms: "hard" and "soft". The former may involve a range of production techniques, including statistical process control, quality function deployment, design processes and procedures of the organisation. The soft side is largely concerned with creating a customer awareness within an organisation, and as such may be seen as a form of internal marketing or employee communication.

This small overview of TQM illustrates the deep interrelation between Quality and Lean Manufacturing objectives.

3.2.3. Quality strategy

Development of quality strategies requires particular corporate culture and organisational behaviour and, therefore, can only be achieved through active leadership supported by top management. The leadership requirement involves a profound knowledge of the organisation [DEM86], namely, process variability, process capability, human psychology, people and customer's needs. It is the starting point for the quality implementation. The next step in the quality strategy is the definition of the organisation mission statement and its management strategies. A mission statement in this context is a statement of the intention of the organisation to change and should be accompanied with correspondent corporate goals. Most organisations formulate their own strategies [KAN92]. The major aim of the quality strategy is to integrate all planning processes of the organisation under the philosophy of total quality management to achieve the quality goals.

The strategic approach to quality has incorporated statistical process control, inter-functional teams to co-ordinate engineering and manufacturing needs, excellence of all managerial, operational and administrative activity, a culture of continuous quality improvement, the creation of customers' and suppliers' relationships, involvement of all personnel, and market-oriented organisation practices. These are also objectives for Lean Manufacturing. Figure 6 shows the interrelationships between quality dimensions and Lean Manufacturing main characteristics. These relationships justify the importance of Quality as a main strategy in modelling for Lean Manufacturing.

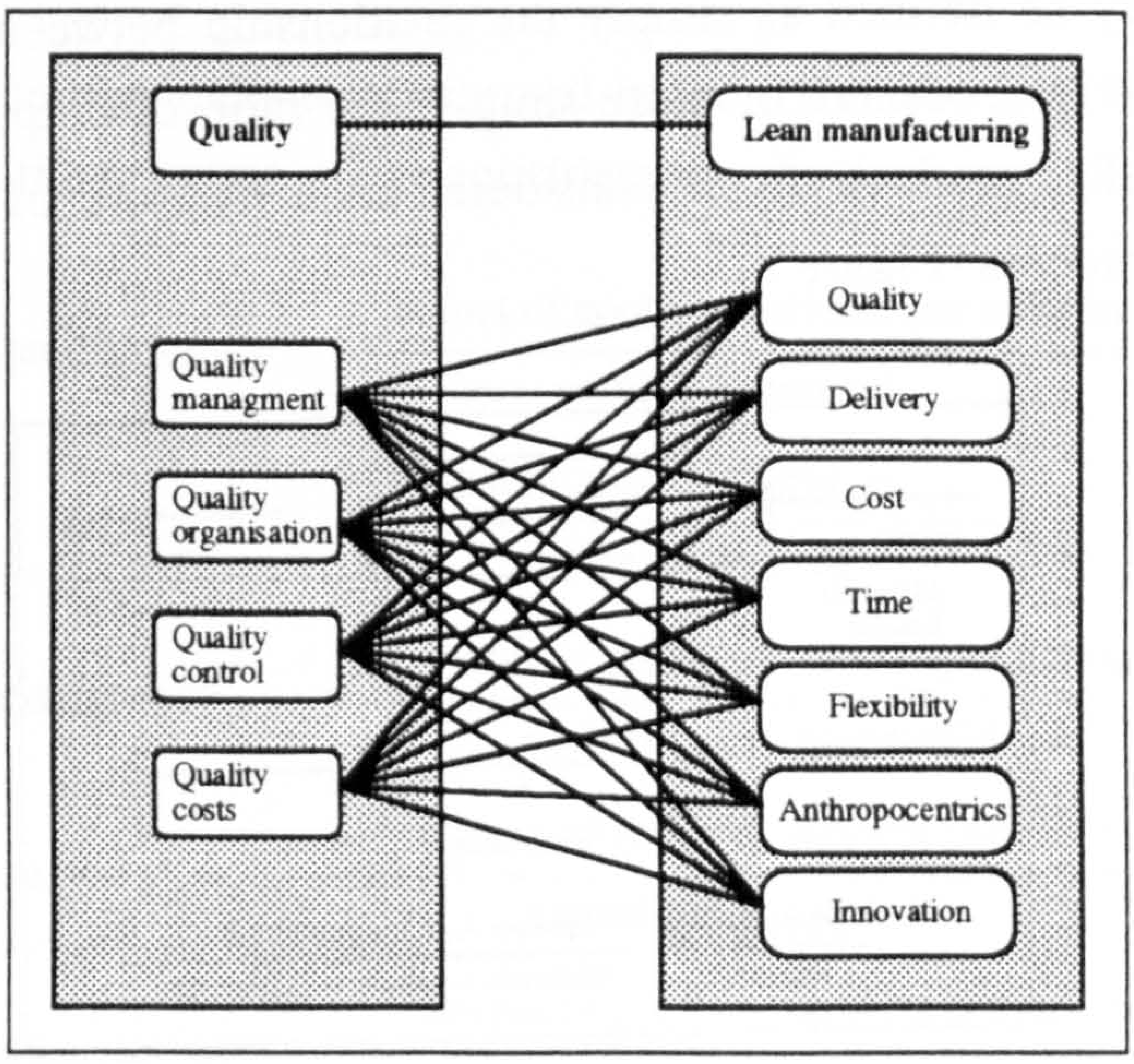

Figure 6 - Quality strategy for Lean Manufacturing

3.3. Performance measurement

The following sections present possible model variables, to be used by lean companies, and include different scenarios to evaluate them. It must be understood that no one uses all of these measures; they are given to show the kinds of measures that make sense in a Lean Manufacturing environment and are not intended to be used as a blueprint for any particular company. The proposed model is presented in section 3.4. The application of the model to the present research in the TCI impose some adaptations.

3.3.1. Productivity

3.3.1.1. Aspects

Companies have different approaches as to how productivity should be defined or measured. Researchers define productivity as a concept which is concerned with efficient utilisation of resources, and some type of ratio of production output to resource input is commonly used as a measure. However, focus is generally on a particular type of resource, which is then a partial productivity measurement [SUM84]. Some authors suggest that improvements in quality level do not necessarily lead to improvements in productivity. Deming's opinion is [DEM86]:

> Improve quality. You automatically improve productivity, you capture the market with lower price and better quality. You stay in business, and you provide jobs. So simple.

Productivity may be defined as simply the relationship between what goes into the system and what is produced, or more simply, the ratio of output to input [SUM84, MIS92]. Typically, productivity is considered as a measure of the efficiency of a transformation process (Figure 7).

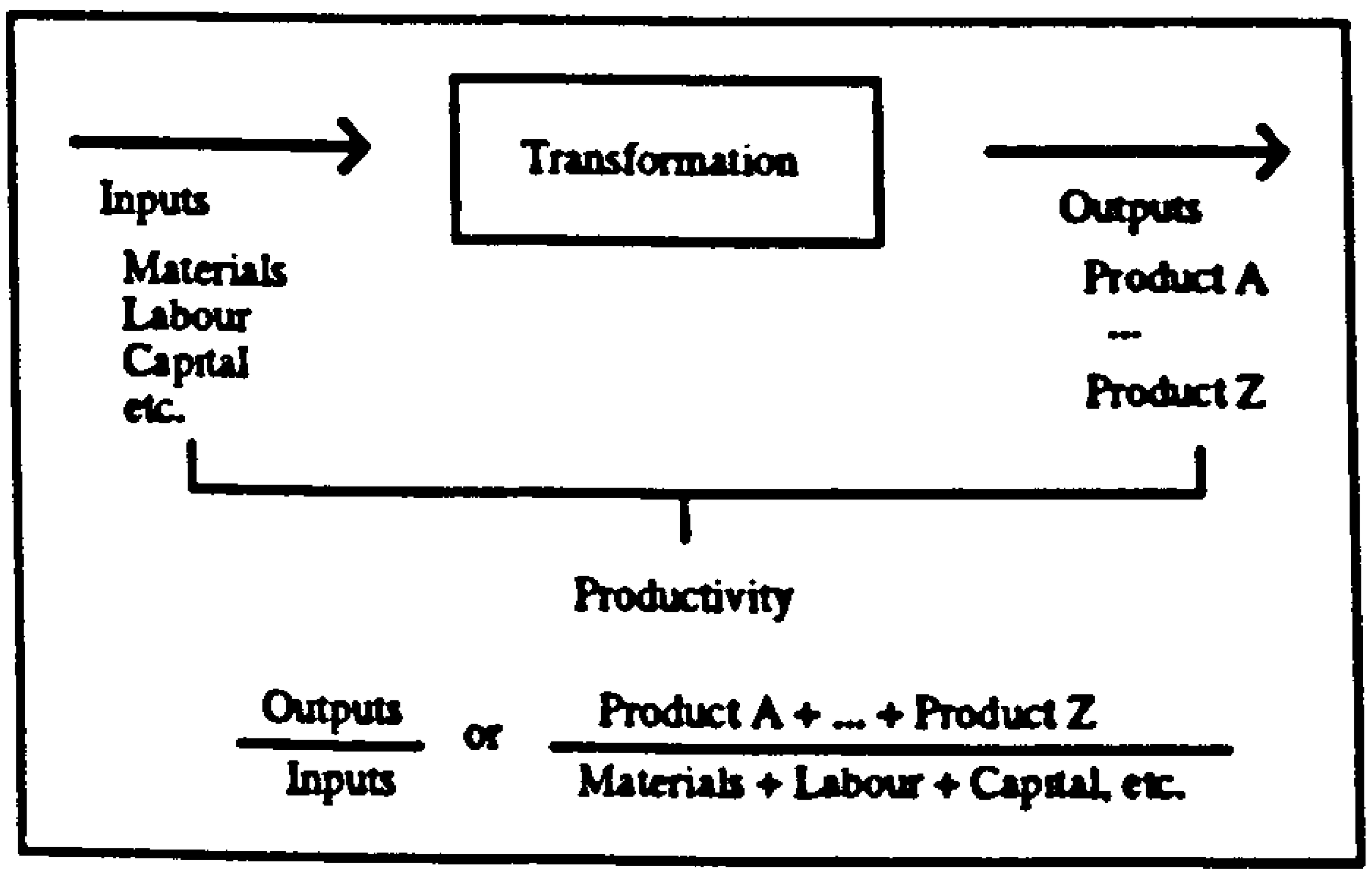

Figure 7 - Productivity is measured as Outputs/Inputs

Deming sees quality improvement as a continual, never ending process. Continuous improvement means gaining knowledge of the process so that the performance of the process can be improved, variability can be reduced, and the process can be improved continuously. Such continual improvement results in improved productivity, but not all of it is directly measurable. As the process is improved, costs decrease owing to improved yields and a reduction in scrap and rework. Productivity measures capture the savings associated with improved use of inputs. However, the improved productivity associated with improved quality of outputs may not be captured. The reduction of costs due to improved process quality together with competitive pressures may result in the same or even lower prices for higher quality outputs.

Classically, productivity measures do not encourage companies to think in terms of the benefits of higher quality. Productivity measures encourage cost reduction reflected in changes in the denominator (input) rather than in improvements in the numerator (output). Productivity measures only give a partial snapshot of the competitive performance of a company. These measures must be complemented with other performance measures.

Productivity is one of the elements in determining the long-run success of a company. At the national level, a deterioration in productivity can lead to relatively low economic growth rate, high inflation, unfavourable balance of international payments, and even impact on standards of living [SUM84, MAD92].

3.3.1.2. Measures

Productivity may be conveniently expressed in the form of a fraction, output forming the numerator and the resource under consideration the denominator [GED79]:

$$\text{manpower productivity} = \frac{\text{output of goods or services per unit time}}{\text{persons employed}}$$

$$\text{or} \quad \frac{\text{output of goods or services}}{\text{man-hours used}}$$

$$\text{material productivity} = \frac{\text{output of goods or services per unit time}}{\text{units (or cost) of material used}}$$

$$\text{capital productivity} = \frac{\text{output of goods or services per unit time}}{\text{capital assets employed}}$$

$$\text{energy productivity} = \frac{\text{output of goods or services per unit time}}{\text{quantity or cost of energy consumed}}$$

Productivity is a straightforward concept, but its quantification presents some difficulty. Efficiency, unlike productivity, is expressed not in absolute but in relative terms. It is the ratio of actual output, using given resources, to the standard output that should be obtained with those resources in the same time period. Thus considering the resource of direct labour,

$$\text{labour efficiency} = \frac{\text{actual output per man-hour}}{\text{standard output per man-hour}}$$

$$\text{or} \quad \frac{\text{actual labour productivity}}{\text{standard labour productivity}}$$

This concept enables productivity comparisons to be made on the same process at different times, or between different processes within the organisation, provided standards are unchanged. However, being a comparative ratio, efficiency would give no absolute measure of productivity if change of plant or process method resulted in a change of standards.

Sumanth [SUM80] defined three types of productivity measures:

- Partial productivity is the ratio of gross or net output to one type of input (the most commonly used partial productivity measure is output per labour-hour),
- Total-factor productivity is the ratio of net output (excluding materials from gross output) to the sum of labour and capital inputs,
- Total productivity is the ratio of gross output to all inputs, which include human, material, capital, energy, and other expense inputs.

3.3.2. Quality

3.3.2.1. Assurance

Quality assurance can be defined as the "activity of providing the evidence needed to establish confidence, among all concerned, that the quality function is being effectively performed" [JUR93]. Quality Assurance is defined by the European Organisation for Quality (EOQ) as "all those planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality".

Quality assurance provides protection against quality problems. It is necessary for two reasons:

- External reasons: give maximum confidence (to client) that a given acceptable level of quality is being achieved,
- Internal reasons: give maximum confidence (to management) that a given acceptable level of quality is being achieved with minimum total expenditure.

The assurance comes from evidence. The evidence is usually some form of inspection or testing the product, or reviewing production plans and auditing the execution of plans. The formalisation of the quality assurance system assures that technical requirements are complied with. It presents the following additional advantages:

- Providing a systematic approach to the activities can affect quality from design to manufacture,
- Stress prevention activities rather than relying on inspection,
- Provide objective evidence (documents) that quality was achieved.

It can also be justified by legal and/or contractual requirements or by other economical and safety reasons. Another aspect is related to the enhancement of communication channels between company departments, with recognised effects on the overall efficiency of the whole organisation. It is an important step to total quality management. In addition, other reasons can be given to a company to implement a quality system, namely:

- Customers and/or potential customers require it,
- Competitors already have formal quality systems and are using them successfully as a commercial weapon,
- Competitive position is affected or even compromised by non quality costs (repair, rework, scrap, delays, claims),
- A certificate of "Qualified company" requires a formal quality system.

An effective quality system, generating accurate information and operated by trained personnel, facilitates control and management of the quality related activities and better assurance of quality.

3.3.2.2. Costs

Some companies with traditional views assume that, beyond a certain point, investing in quality becomes subject to diminishing their returns. Such a view fails to see quality as a strategic issue and fails to understand that the cost of quality is much wider than scrap and reworking. When quality is improved creatively, cost is reduced and productivity is increased. Kondo [KON90] points out that "it is only 200 years ago that people began to discuss productivity whereas cost and quality has been considered for thousands of years".

Traditionally approaches to quality costs were concerned with finding the *optimum* amount of effort to be put into improving quality, Figure 8.(a). Current practice is illustrated in Figure 8.(b). The important aspect is that these figures shows two kinds of costs: the costs of providing quality (quality costs) and the costs of errors (non-quality costs).

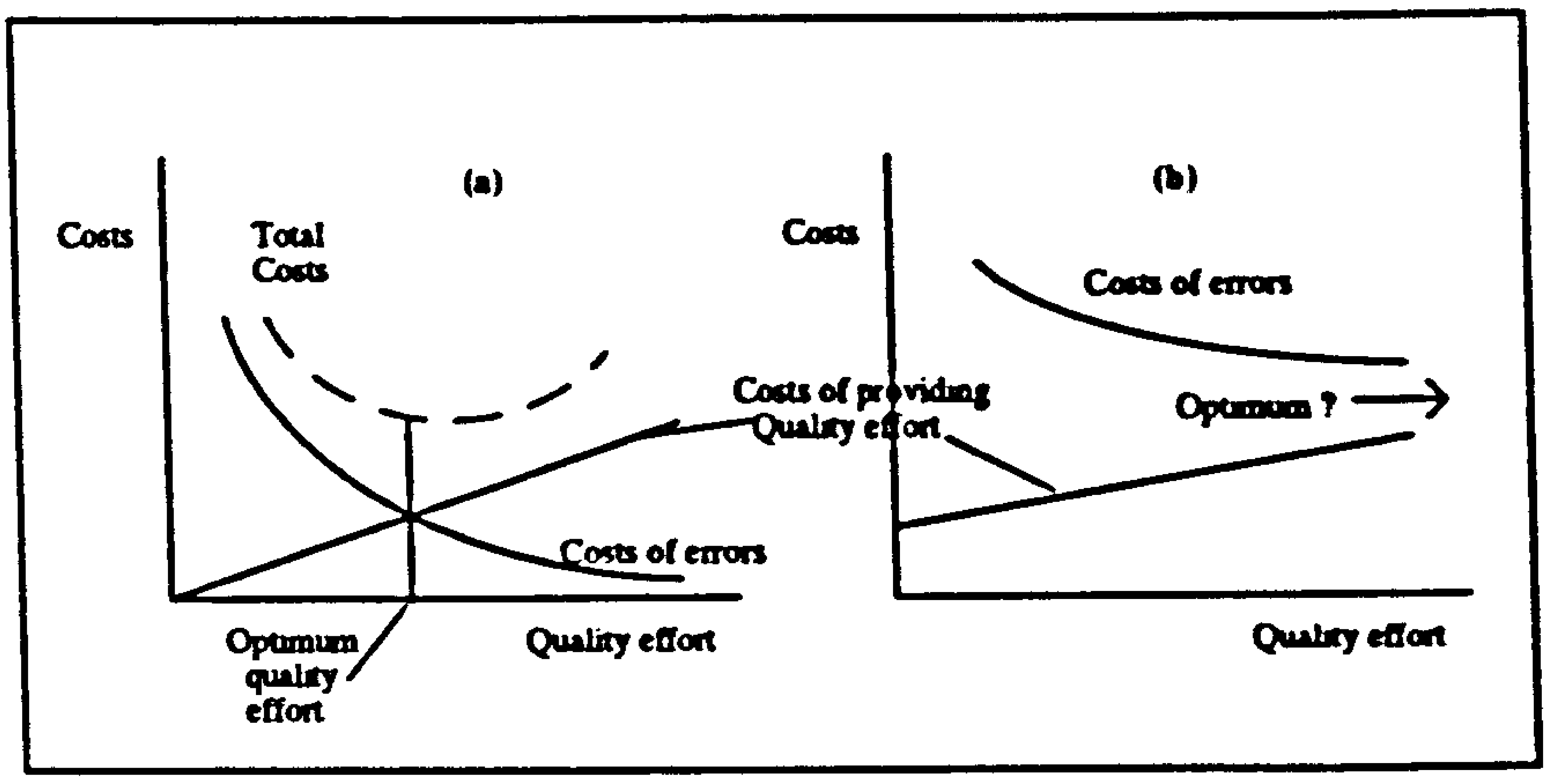

Figure 8 - Quality cost/benefit analysis

3.3.3. Delivery

3.3.3.1. The D:P ratio

Delivering goods on time to the customer is the culmination of a long series of steps being done right. Traditional companies achieve these objectives by holding large inventories. This can be illustrated from an analysis of the D:P ratio (D - delivery lead time, P - production lead time), Figure 9. If the value of D is greater than P, then the product can be made to order. If the value of D is less than P, the product must be made to stock. If the D:P ratio is small (less than 1), the manufacturer is able to offer more flexibility to the customer. This flexibility includes product mix changes, production volume changes, and custom products. If the D:P ratio is large (greater than 1), the manufacturer must forecast customer needs and can only provide flexibility of mix and volume by holding additional finished products inventory.

Custom products cannot be supplied within the delivery lead time because there is not enough time to make them. The D:P ratio is a measure of success at improving delivery lead times and production flexibility.

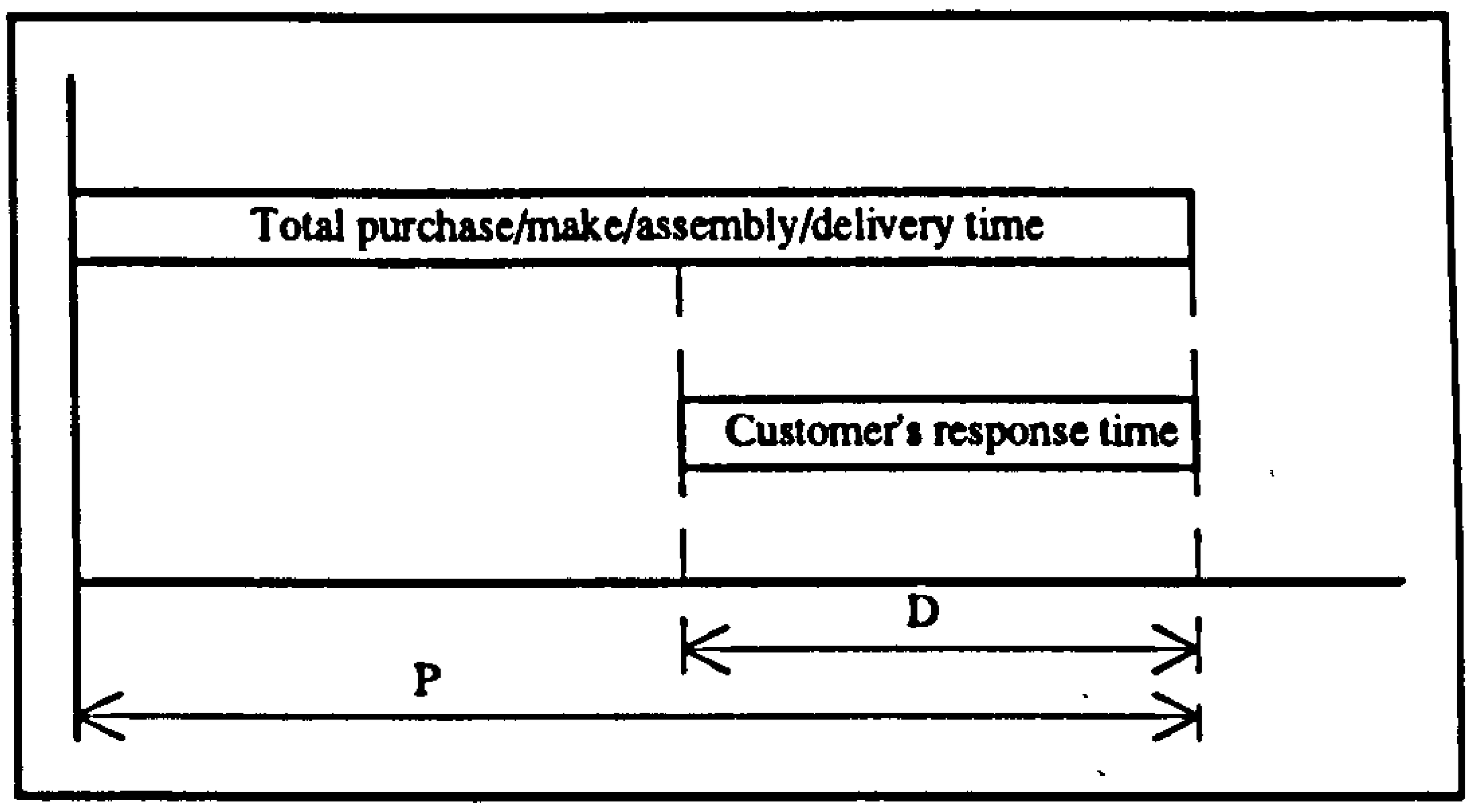

Figure 9 - The D:P ratio

3.3.3.2. Measures

In a Lean Manufacturing environment the delivery process can be assessed with appropriate performance measures, namely:

- Timeliness of delivery
- Past due orders
- Delivery lead time
- Average lateness of delivery
- On-time schedules and schedule adherence by work cell
- Effectiveness of the shop floor schedules (expressed by the number of changes over time)

3.3.4. Time

3.3.4.1. Manufacturing cycle

The term *lead time* captures the time that a part spends in a manufacturing system. There are two variants of lead time discussed in the literature, namely manufacturing lead time and total lead time:

- *Manufacturing lead time* (MLT) is the total time required to process the product through the manufacturing plan,
- *Total lead time* (TLT) is the total time elapsed from the instant at which raw materials are ordered until the instant the finished product is delivered.

Ideally, MLT should be equal to the actual sum of operations times. This is possible with zero inventories, zero material handling, zero setup time, zero defects, zero breakdowns, and a batch size of one. The TLT includes procurement, vendor, manufacturing, engineering, tooling, and customer lead times. If we focus on manufacturing lead time we can find that MLT includes the following components: setup time; processing time; move time; and queue time.

While focusing on MLT, we assume that raw materials are currently in stock (procurement lead time is zero and that we have made these items before; we have on hand the design, the process plan, and the necessary tooling). In a typical processing environment, the MLT is much greater than the actual processing time for the batch. In conventional batch processing, actual processing time and setup time together represent less than 5% of MLT [GHO91, PRI91]. Queuing and transport times account for the rest of the MLT. The ideal cycle time would consist entirely of value-added activities; in other words no queues, wait time, or wasted activities. Long cycle times are obstacles to Lean Manufacturing because they cause: high work in process; high finished goods inventory costs; high probability of costly changes (in engineering, order quantities, processes) during the production process; and inflexibility.

3.3.4.2. Set-up

A typical production facility will have hundreds of different setup procedures. There are two primary methods of measuring the setup times. One way is to count the number of setups and divide them into ranges according to the length of time taken to achieve the setup. The second approach is to calculate the average time taken to perform a number of setups over a time period within each work centre.

3.3.4.3. Machine up-time

For Lean Manufacturing excess inventory must be eliminated throughout the production process. This means a high degree of reliability in the production process. Machine breakdowns or stops in the production process cannot occur. To prevent that, production equipment is not used at 100% of capacity. A certain margin is left for maintenance purposes. This procedure assures a better machine up-time when it is really required to run.

3.3.4.4. Time-to-market

The speed of introduction or *time-to-market* is a measure of the company's effectiveness at converting ideas into products. This process can be measured by keeping track of when a project was initiated and when it was completed and the new product launched on to the market. The time-to-market is the time taken from initiation to completion.

3.3.4.5. Materials residence time

The time which material takes to move in the production cycle is either taken in being processed, travelling between stages, or waiting to be processed. Waiting time is by far the largest element in the throughput cycle, including the time of raw materials and finished products in warehouse.

3.3.5. Cost - Financial

Cost is at the centre of manufacturing objectives as it has a direct impact in competitiveness. Lower costs may significantly enhance competitiveness or directly increase operating margins.

3.3.5.1. Inventory costs

The stock turns and the number of days of stock are important measures of inventory levels. By stock turns we mean the number of times the inventory is totally used within the year. Although stock turns is expressed as a non-financial measure, it is calculated from the financial measures of inventory valuation and cost of goods sold.

3.3.5.2. Value added

In the majority of manufacturing plants the amount of time spent adding value to the product is vary small in comparison to the total production lead time. The majority of the time is spent on non-value-added activities. The important is to analyse what, within the production process, adds value to the product and what is waste. The relationship between these values gives a measure of value-added and wasteful operations.

3.3.5.3. Production costs

The production costs represent all the costs related to value-added and non-value-added activities: processing, moving, waiting, inspection, setting up, overproduction, stocks, reworking. There are other important cost measures which purpose is to monitor the changing characteristics of plant costs over time, namely:

- *Cost per unit* - is determined by dividing the total production costs by the number of units manufactured. This measure gives an indication of the effect of all the cost-saving improvements that have been introduced as a result of implementing a Lean Manufacturing approach.
- *Cost of adding value per unit* - is similar to the cost per unit except that it is concerned only with the costs of adding value to the product, not with the total product cost. By removing the material and outside process costs from the calculation, this measure focuses on the plant's productivity.

3.3.5.4. Measures

Reliance on pure financially based performance measures should be avoided by lean companies because non-financial measures are clearer, more relevant, and easier to use. However, they can be used to explore whether the "intangibles" do indeed provide benefit to the company in the long term. Financial measures include:

- Growth - is the annual incremental change in turnover expressed as a proportion of initial turnover
- Labour efficiency - is a measure of how well the workforce performs. It is derived from Value Added divided by the number of employees.
- Employment efficiency - is a measure of the labour performance. It is defined as Value Added divided by employment cost.
- Capital efficiency - is Value Added divided by Capital Usage. Capital Usage is depreciation plus rents and leases excluding finance charges.
- Conversion efficiency - is the summation of the labour and capital inputs compared with the output in terms of value added.
- Profitability - is the return of sales (pre-tax profit divided by turnover)

3.3.6. Flexibility

There exists confusion concerning how to define the concept of flexibility. One result is the misconception that flexibility may cause the decline of productivity. The focus of international competition has changed from cost to quality, reliability, and the ability to respond quickly and accurately to customer needs. The latter is what is called flexibility.

3.3.6.1. Change over time

Changing circumstances include both internal and external changes. Internal changes or disturbances include breakdown of equipment, variability in processing times, worker absenteeism, and quality problems. External changes are typically changes in design, demand (reduced size of orders, rapid deliveries, low inventory policies), and product-mix. The ability to cope with internal changes requires a degree of redundancy in the system, whereas the ability to cope with external changes requires that the system should be versatile and capable of producing a wide variety of part types with minimal changeover times and costs to switch from one product to another.

The time to process an order and the product variety that can be produced will decide the competitiveness of the manufacturing system. From the definition of flexibility it is clear that *flexibility* is fundamental to achieve *competitiveness*. Also, *flexibility* will provide a strategic advantage to handle risk associated with uncertain markets.

3.3.6.2. Flexibility and uncertainty

Most authors argue that flexibility is normally considered as an adaptive means of handling environmental uncertainties [GER92]. The conversion to flexible manufacturing is complex and requires the consideration of many interrelated factors, namely, design, production and processes.

3.3.6.3. Design, production and processes

Two types of manufacturing systems with different flexibility can be identified. Transfer and assembly lines (as those existing in the TCI) are very effective in producing parts in large volumes at high throughput rates, with the limitation that the parts be identical. These highly mechanised lines are very inflexible and will not easily tolerate variations in part design. In transfer lines, failure of any of the machines would bring down the entire line and thus there is no fault-tolerance.

Job shops are highly flexible (*i.e.*, it can accommodate design demand and product-mix changes, and can tolerate machine failures). However, in a typical job shop lead times are very high. The design, process planning, setup tool procurement, and changeover times all add up to long lead times. Although job shops are highly flexible, they usually suffer from large MLT and high WIP.

3.3.6.4. Measures

Hill [HIL91] shares the opinion that appropriate measures for flexibility have not been developed but they are essential if adequate and relevant analysis of company performance is to be undertaken. Crowe [CRO92] argues that any measure of flexibility must include two components: a measure of diversity and a measure of time. Diversity appraises the amount or degree of change (ex: number of parts, number of part families, percentage change in volume, and number of setups). The time measures allow rates and frequencies to be calculated (ex: time between part family switchovers, percentage change in volume per business cycle, and number of setups per forecast period). We can define several measures of flexibility:

- *Machine flexibility* measures the ease with which a machine can change over from one part type to another.
- *Product design flexibility* is a measure of the ability to change over to a new product-mix economically and quickly.
- *Routing Flexibility* measures the ability to manage internal changes such as breakdowns and failures.
- *Operation Flexibility* is the ability to interchange the ordering of several operations for each part type.
- *Materials flexibility* is the ability to change raw materials without affecting the manufacturability of the products.
- *People flexibility* is the ability to have production personnel moving from one task to another, without loosing efficiency.

3.3.7. Innovation

Innovation refers to the ability of a company to introduce new and better products to the market quickly. The most frequently used indicators are the lead time of new product introduction and the number of new products launched per period. The number of new products can be measured by keeping track of a new product release and counting how many releases occur within a time period.

3.3.8. Anthropocentric issues

3.3.8.1. Change

The new Lean Manufacturing environment calls for employees that possess features such as multiskills, initiative, participation, objectivity, quality deployment, confidence, ability to cooperate, willingness to solve problems and the principle *"the next step is my customer"*.

3.3.8.2. Motivation

A theory of motivation put forward by Maslow is that man's needs can be arranged in an order of prepotency and that, when the basic physical needs (e.g. food, clothing, shelter) have been satisfied or nearly satisfied, their motivating power tends to disappear and other needs, more of a psychological nature (e.g. status, recognition, friendship), come into prominence. When Taylor started his work in the 1880's the attraction of a substantial advance in earnings was a more powerful output incentive then it would be today. In many cases, where improved methods and higher productivity were in the past rewarded by a handsome increase in earnings, after the new wages have run for some time they become accepted as a normal entitlement and the motivating power tends to fall off. Furthermore, with the shift of production methods towards automation, work study techniques have often become less applicable, although motivation for a better performance remains as important as ever.

The measure of motivation is not straightforward. It must be seen from the viewpoint of: what management must do to motivate people. Issues like training, improvement projects, giving responsibilities, can be real evidences of motivation efforts.

3.3.8.3. Communication

For most companies, achieving a truly Lean Manufacturing environment requires a significant organisational change. Although the organisational structure will vary among companies, there appear to be common organisational characteristics developing in lean companies. Some of these characteristics are [STA90a]:

- A reduced number of organisational layers
- Participative management
- Shared and decentralised decision making
- Shifting from hierarchies into networks
- Cross-functional teams
- Culture supporting integration and change

Many companies are delayering themselves and cutting management positions. At the same time, companies are producing more with less direct labour because of better work methods and automation. The trend toward a flatter organisation is attributable not so much to automation as to business factors [SAV90].

Peter Drucker [DRU92] has suggested that business should have only half as many levels of management as are typical today (Figure 10). In addition, the organisations of the future should be knowledge-based, an organisation composed largely of specialists who direct and discipline their own performance through organised feedback from colleagues, customers, and suppliers [SAV90].

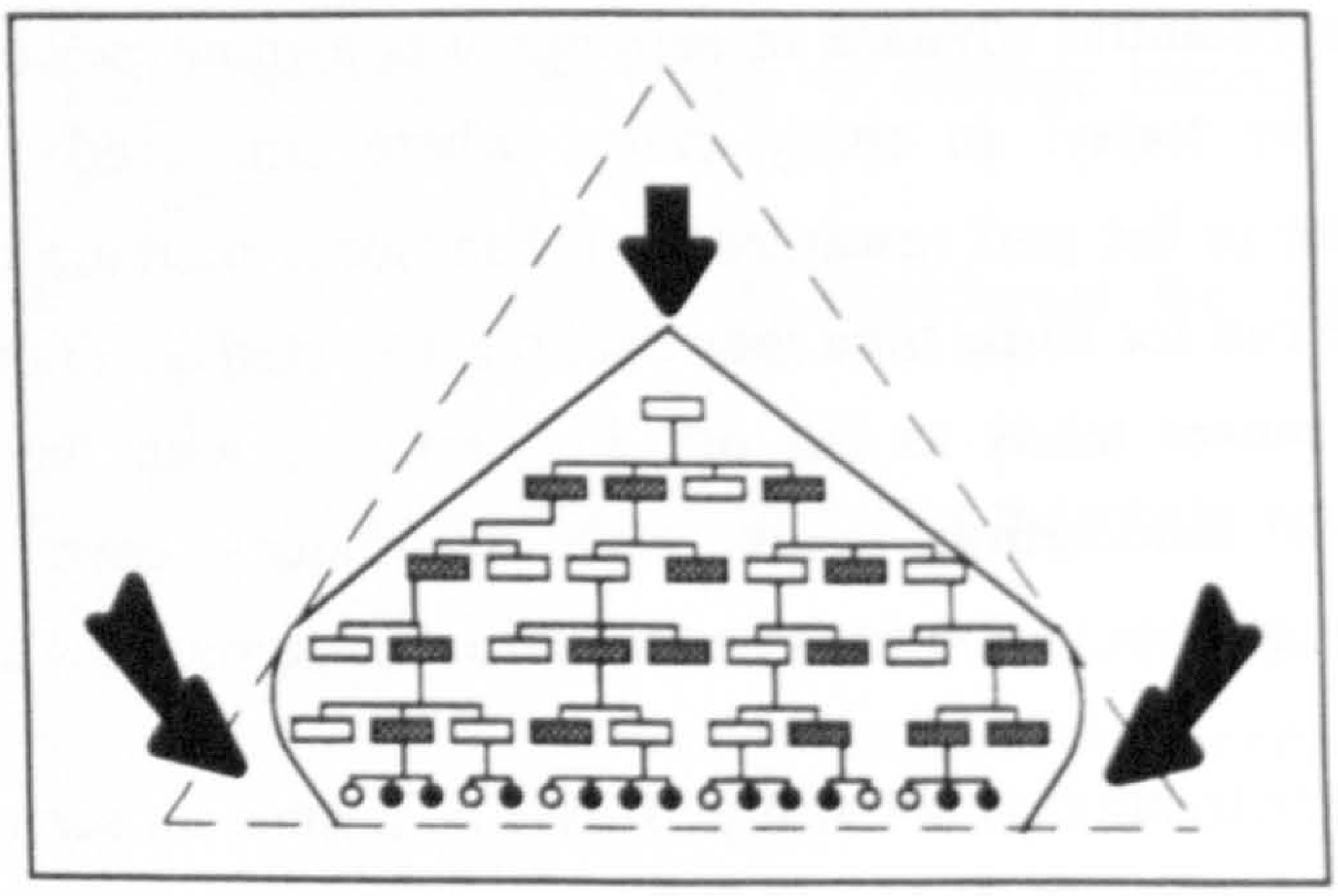

Figure 10 - Hierarchies under pressure

No traditional corporate structure, regardless of how delayered, can gather the speed, flexibility, and focus that success today demands in the lean environment [CHA91].

The shift from relatively stable to dynamic markets with increased knowledge and information requirements needs reorganising in *networks* [SAV90] (Figure 11).

Networks differ from teams, cross-functional task forces, or other *ad hoc* innovations designed to dismantle hierarchy. Networks unlike most teams and task forces, are not temporary. In addition, they do not merely solve problems that have been defined for them. Networks are dynamic; they take initiative. Finally, networks make demands on senior management that teams and task forces do not.

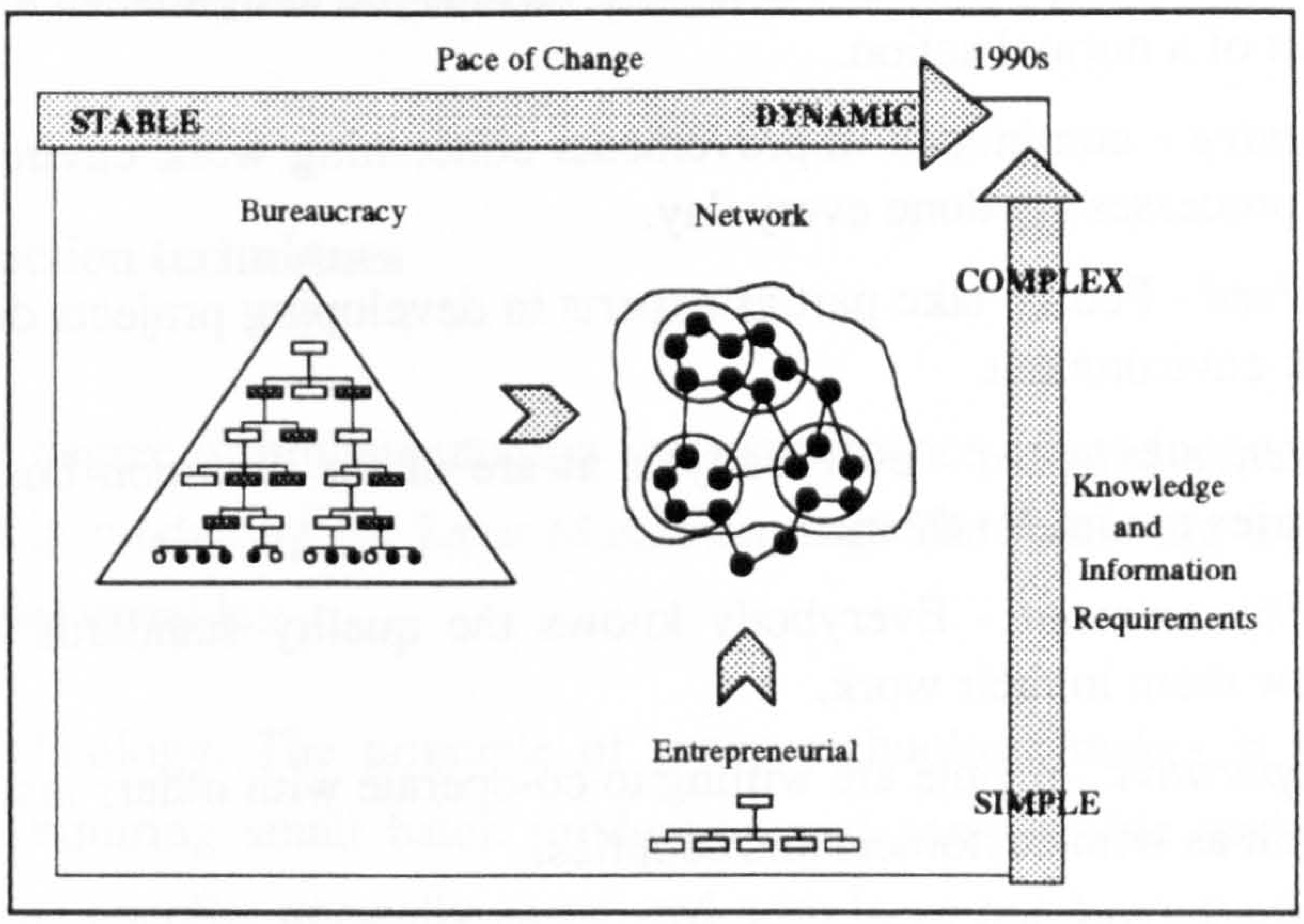

Figure 11 - Organisational forms and environmental demands [SAV90]

3.3.8.4. Crossfunctional teams

Lean organisations have implemented cross-functional teams - teams that work without organisational barriers - as a part of the new work force management policies. Kumar [KUM91] found that teams can be used to reduce time-to-market, select and plan new innovative projects, enhance the quality of an organisation's products and services, or achieve self-management in innovative settings. Members of a true cross-functional team should consist of all levels of management, operators and technicians, and members from different organisations, including vendors and customers.

According to Kumar, cross-functional teams encourages interaction, promotes positive outcomes such as increased motivation, stimulation of ideas and relevant knowledge, more creative individual problem solving, and a new framework to view organisational problems. It also gives an operator an opportunity to communicate his ideas directly to upper management.

3.3.8.5. Training

To be successful, Lean Manufacturing requires skilled, motivated, and committed personnel and management. Human resources have to have the following characteristics [WIL92]:

- *Multi-skilled* - personnel can handle various job assignments and the rotation is a part of a normal action.
- *Initiative* - continuous improvements concerning work environment, product, and processes are done every day.
- *Involved* - People take part as experts in developing projects dealing with their work environment.
- *Objective oriented* - everybody is aware of the common business objectives and tries to aim for them.
- *Quality oriented* - Everybody knows the quality standards and are able to follow them in their work.
- *Co-operative* - people are willing to co-operate with others inside the company as well as with customers and supplies.
- *Confident* - there is a sense of integrity inside the company.
- Aware of the principle "*the next step is my customer*" - everybody keeps hold on the delivery times both inside and outside the company.
- *Willing to solve problems* - personnel deals with problems and tries to create solutions.

The roles of individual employees and managers are very different today and drive the lean company to heavy educational commitments, and new approaches to selection, evaluation and compensation. These changes also require considerable sensitivity to minimise management and employees' fear. Education and training become more critical in the lean company. Employees are asked to participate actively in process analysis, problem solving, group self-management, and take business responsibility for performance. Long term success will depend on effective management of human resources by executives, which means providing valuable benefits to its employees and providing opportunities for growth and stimulation to its human resources.

3.3.9. Technologies

In modelling for Lean Manufacturing the technological performance is a vital issue. Technologies must be effectively used. However, as it was seen in section 2.2.4, usually investment in technology does not give the expected results. This is the reason why technology is an important model variable that must be assessed. Technology does not mean only production equipment. It means also the use and domain of automation support, CAD/CAM, materials handling, warehousing, systems integration, and equipment availability.

3.3.10. Production techniques

Measuring the degree of implementation and performance of production techniques is also proposed in modelling for Lean Manufacturing. The following were considered important model variables:

- Group technology. The principle of group technology makes it possible for a situation requiring small batch production and considerable variety to achieve some of the benefits normally associated with large batch production and a high degree of standardisation. These benefits include: to reduce materials handling costs, to reduce work-in-progress, easier and more effective supervision, to improve skills leading to quicker set-up times, and to increase standardisation.

- Inventory management. The control system of stocks depends on an efficient planning and control of production. All forms of consumable stores are increased by purchases or by the output of the supplying process. In the absence of co-ordinated stock control policy, most of the pressures exerted tend to push stocks levels up. The investment in stock will become too high. Stock control will avoid this situation.

- Just-in-time. JIT is a production management philosophy that focuses on eliminating waste and inefficiency by reducing inventory. Typically the techniques of JIT reduce order lead time, setup time, and delivery time with the goal of reducing inventory. The ultimate realisation of just-in-time would be a completely synchronised and integrated network of operations, in both production and purchasing, with zero inventory in process. This requires the material to be at the right place at the right time, and the production planning and control should be based on pull instead of push. A key to JIT success is in simplifying everything that is complex.

- Product design. The design of new products is one of management's most important tasks and involves the co-operation of research, design, engineering, production and marketing. Design for manufacturing and concurrent engineering are concepts to assist the design process.

- Production planning and control - MRP. The lack of adequate production planning and control systems can cause the failure of a company that intends to become lean. An integrated production planning and control system provides a better stock control in all production phases. It allows reducing inventory costs, improving the work flow and reducing production lead time.

- Work study. This helps to design assembly lines to give as nearly as possible the same amount of work for each operation, making possible an efficient overall performance and a satisfied team.

- Layout design. New products or new options may need new production processes, and even new or improved facilities. An adequate layout configuration of the facility can help the work-in-process to flow quickly and smoothly. It means a better visualisation of the production process and products, and consequently, reduced lead time and production costs. The layout design of a company shows the care that it puts in improving its processes.

- Maintenance. The implementation of Lean Manufacturing must be accompanied by the introduction of a preventive maintenance programme. Production personnel must be trained to perform basic daily and weekly preventive maintenance tasks.

3.4. Development

3.4.1. The global model

The proposed model presented (Figure 12) has two sets of variables: those that represent main priorities for the company and are directly visible for customers; and those that provide internal background to achieve the objectives of main priorities. The first group includes: Quality; Delivery; Cost; Innovation; and Time and Speed elements. The second group includes: Flexibility; Technologies and Techniques; and Anthropocentric elements.

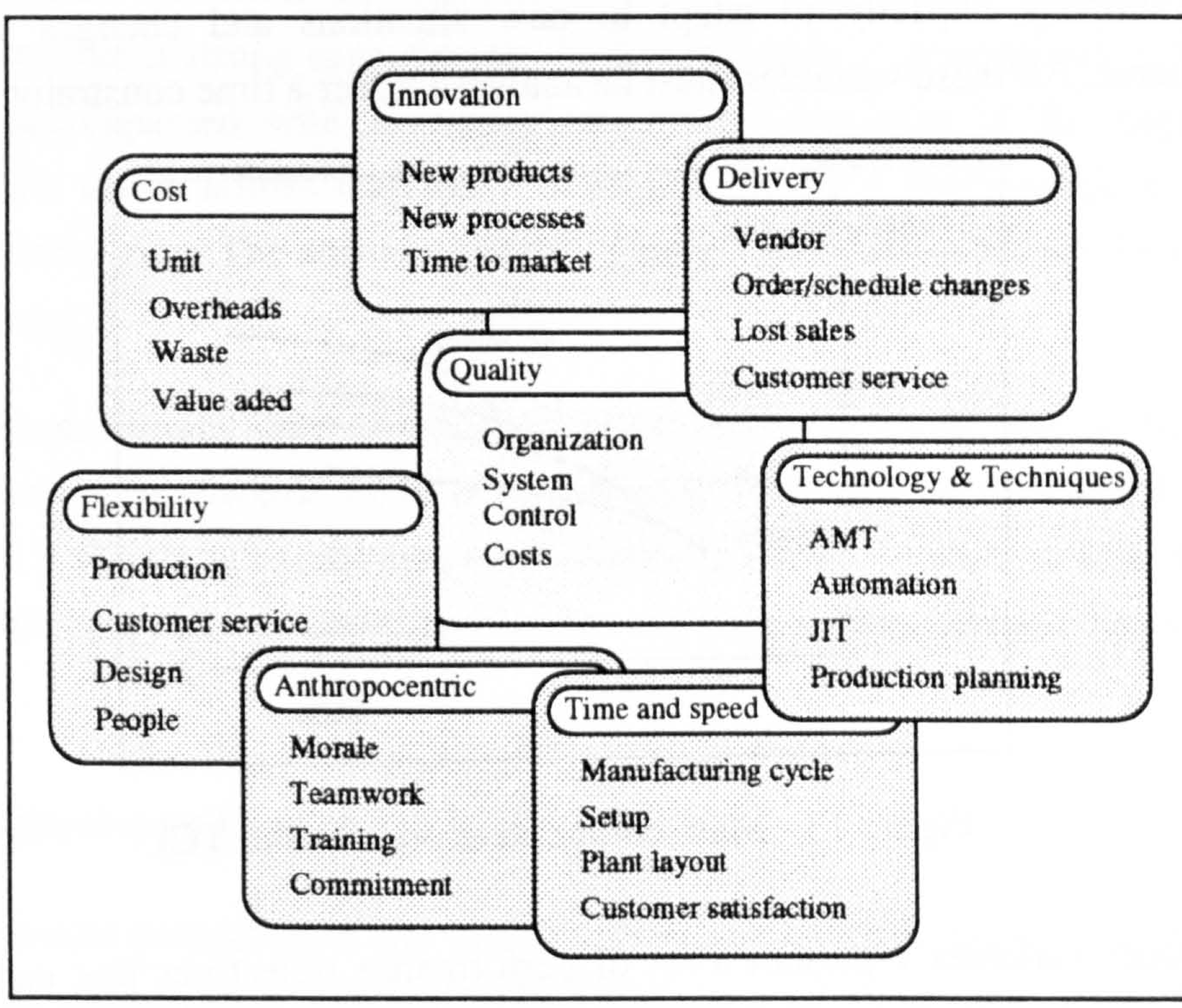

Figure 12 - Model building blocks

This model supplements traditional approaches and provides a more comprehensive insight into how well an organisation is really performing. The proposed model is based on a quality approach:

1. Quality is the first basic competitive advantage. To be in the business, organisations must manufacture quality products. Even if the other variables (delivery, cost, ...) are doing well, it is difficult for a company to sell products of non-consistent quality.

2. Quality is the only variable, supported by a profound and strong theory, that has culminated in the development of well known standards in different quality areas (quality assurance, sampling, inspection, and measuring, to name a few).

The model variables were developed from a review of theory and by observation of industrial practice gained during the first part of this research. The formal analysis (presented in Chapter 5) allowed this model to be built . Figure 13 shows the situation observed in terms of main competitive priorities for the TCI. Quality was identified as the first priority. The second priority is to deliver on time, but it presupposes to deliver the right (quality) product, in the right quantity. The cost variable is not the most important. It presupposes the required quality and delivery. However, if they are achieved, the cost is the next "obstacle" to overcome. Finally, flexibility plays the role of the company capacity to adapt to new situations and changes to customer requirements. All these variables must be analysed under a time constraint analysis.

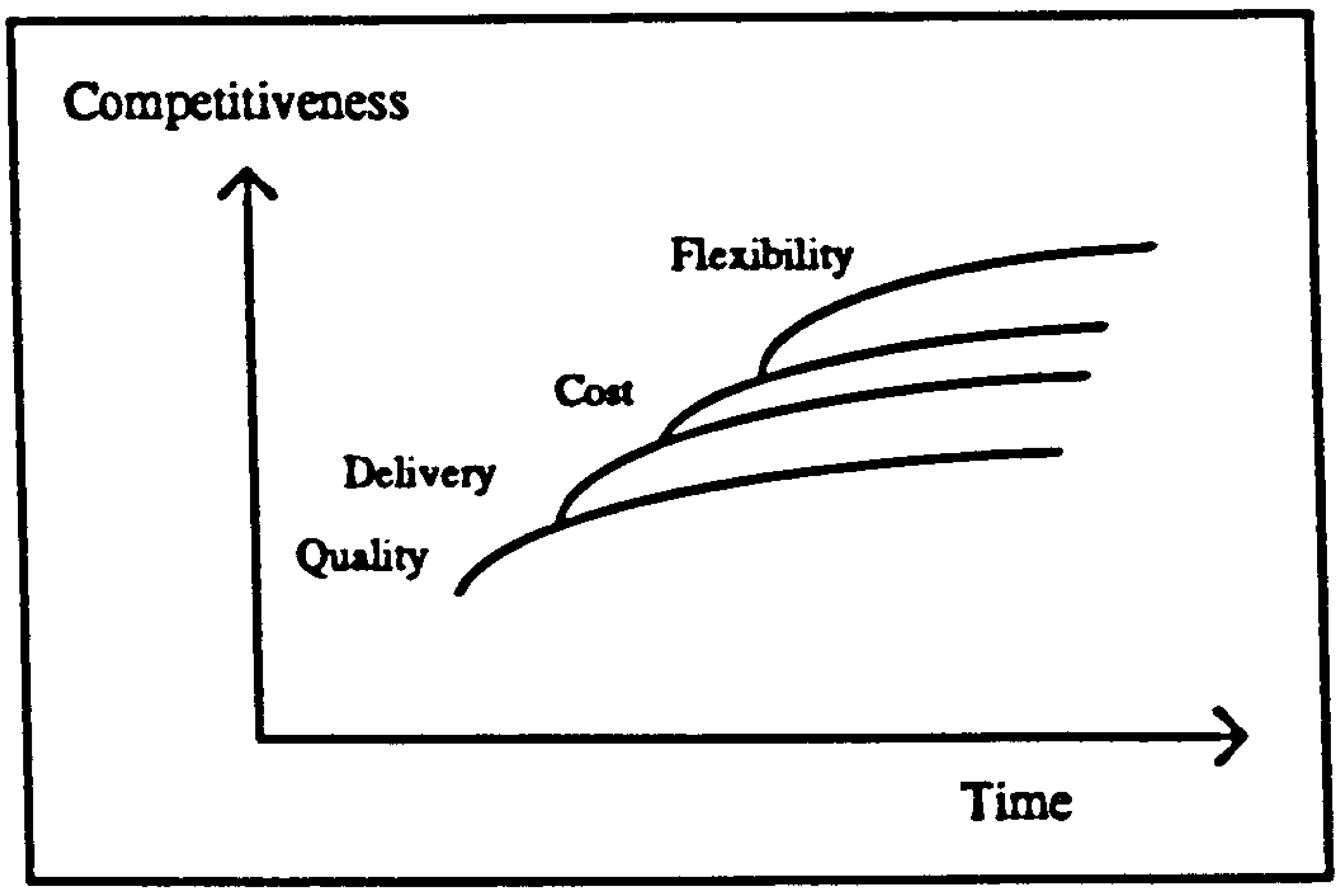

Figure 13 - Main competitive priorities in TCI

These model variables represent a set of performance objectives that can be felt by external customers. In fact, these variables represent an image of the company for the outside world. However, sometimes this image is not so clear for internal "customers". In modelling for Lean Manufacturing, these variables must be highlighted and complemented with internal performance variables of technological achievement in an anthropocentric approach (Figure 14).

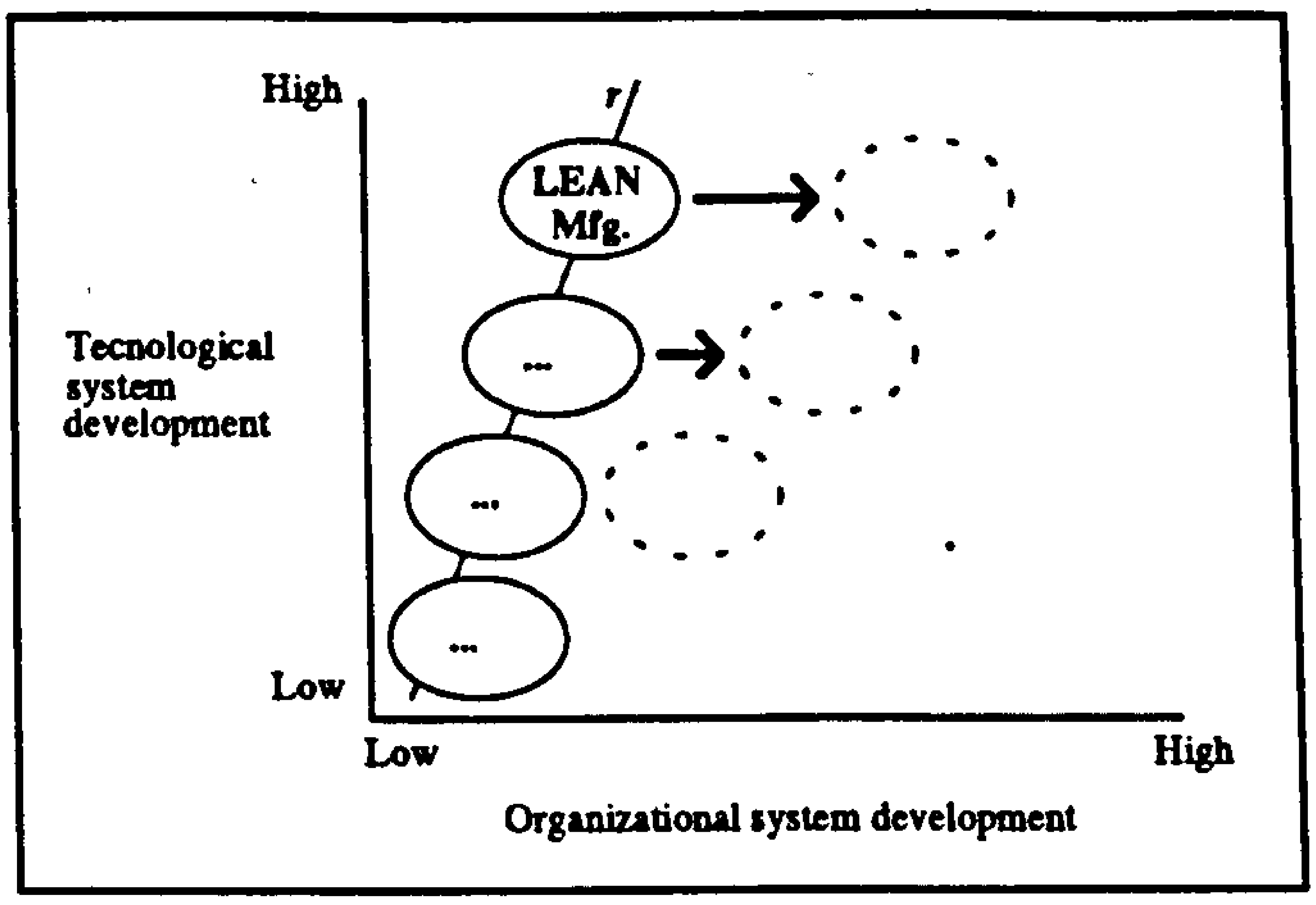

Figure 14 - Anthropocentric Approach

It is the author's conviction that technology alone cannot give the best results without the support from a strong organisation. In this perspective, investment in technology must be accompanied with investment in the development of the organisational system. This action allows that line ***r*** in Figure 14 take a better position to achieve Lean Manufacturing. The anthropocentric approach will help to potentiate a better use of technology.

The model philosophy was designed in two dimensions: it can give an overall company performance towards Lean Manufacturing (this will be developed in section 3.4.3); and it allows us to establish relationships between variables to identify dependencies, which provides an important tool for continuous improvement (section 3.4.4).

3.4.2. Objective and subjective indicators

From the model presented we can identify for each variable a set of indicators that can be used as performance measures. The definition of these indicators depends on several aspects: the industrial sector of the company; the particular company, and even the company strategy. In our research the indicators proposed were derived from the group of textile companies that were studied. In Chapter 5 we justify that this group of companies are representative of the textile industry.

In a first approach we have used indicators supplied by companies. These indicators were called *objective* indicators as they represented figures from the companies, mainly in terms of quality, productivity, and financial figures (Figure 15). These indicators were not found satisfactory. They were only an output from a number of non-identified processes, and they give no information on the performance of those processes. To have a better understanding of a company it would be necessary to assess the way it is performing in its several dimensions. This fact led to the development of *subjective* indicators to assess those areas. The indicators were called subjective indicators because they are not numerical figures. They derive from a qualitative assessment of a specific system/function/process performance.

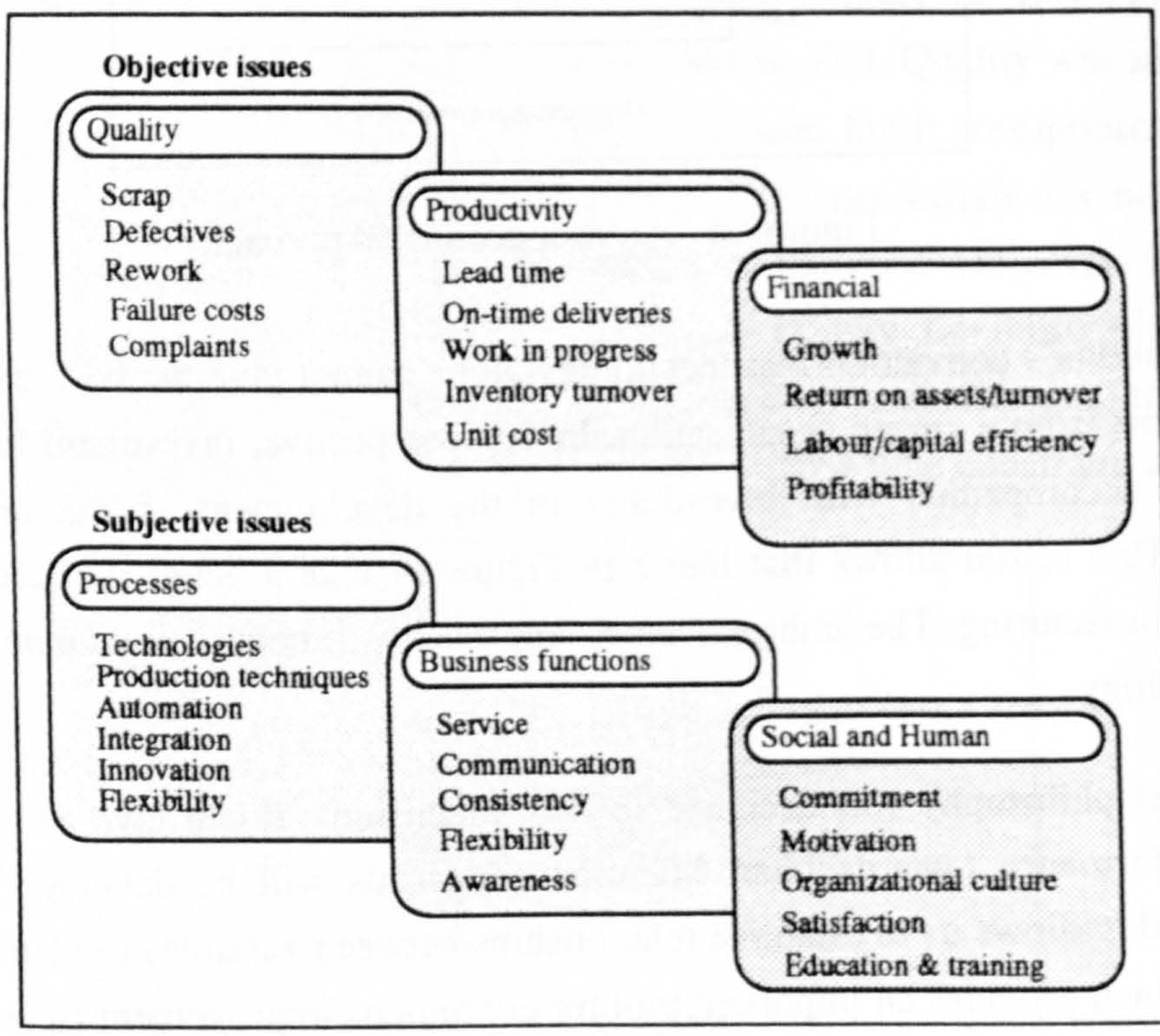

Figure 15 - Objective and subjective indicators

Therefore, the model is made up by variables whose indicators may be objective or subjective. In general objective indicators derive from measures of outputs, whereas subjective indicators derive from measures of inputs. For instance, the Quality model variable is divided in two main characteristics: what do we do to improve it, and; what is the final quality of the products manufactured. The former can be considered as an input. In our model it represents the efforts in implementing a quality system, in controlling, and in prevention actions. The latter is definitely an output. It is the scrap rate, defectives, complaints, and other quality costs. This means that a specific variable can be regarded as an input or an output, according to the indicators that are being used.

In some cases it is difficult to identify whether an indicator is objective or subjective (output or input). For instance, absenteeism can be regarded in both ways. It depends on the perspective. However, it was considered as an objective indicator as it usually is a result of internal organisation.

3.4.3. Evaluation of the Average Level of Performance

The evaluation of all the model variables is required to ascertain how far the company is from the lean status. The evaluation of objective indicators depends on existing data, more or less available in the company. However, in what concerns subjective indicators, a special effort must be done, as it depends on a technical subjective assessment. To help in the assessment process of these variables, a group of checklists was developed (see annexes 3, 4, 5, and 6).

The methodology proposed consists of classifying objective and subjective indicators in five categories or levels of performance. For each indicator a pattern of performance is traced (Figure 16). Even for objective indicators, from which physical values are obtained, the proposed methodology requires them to be converted to one of these five categories. Table 14 in Chapter 4 shows the conversion method used.

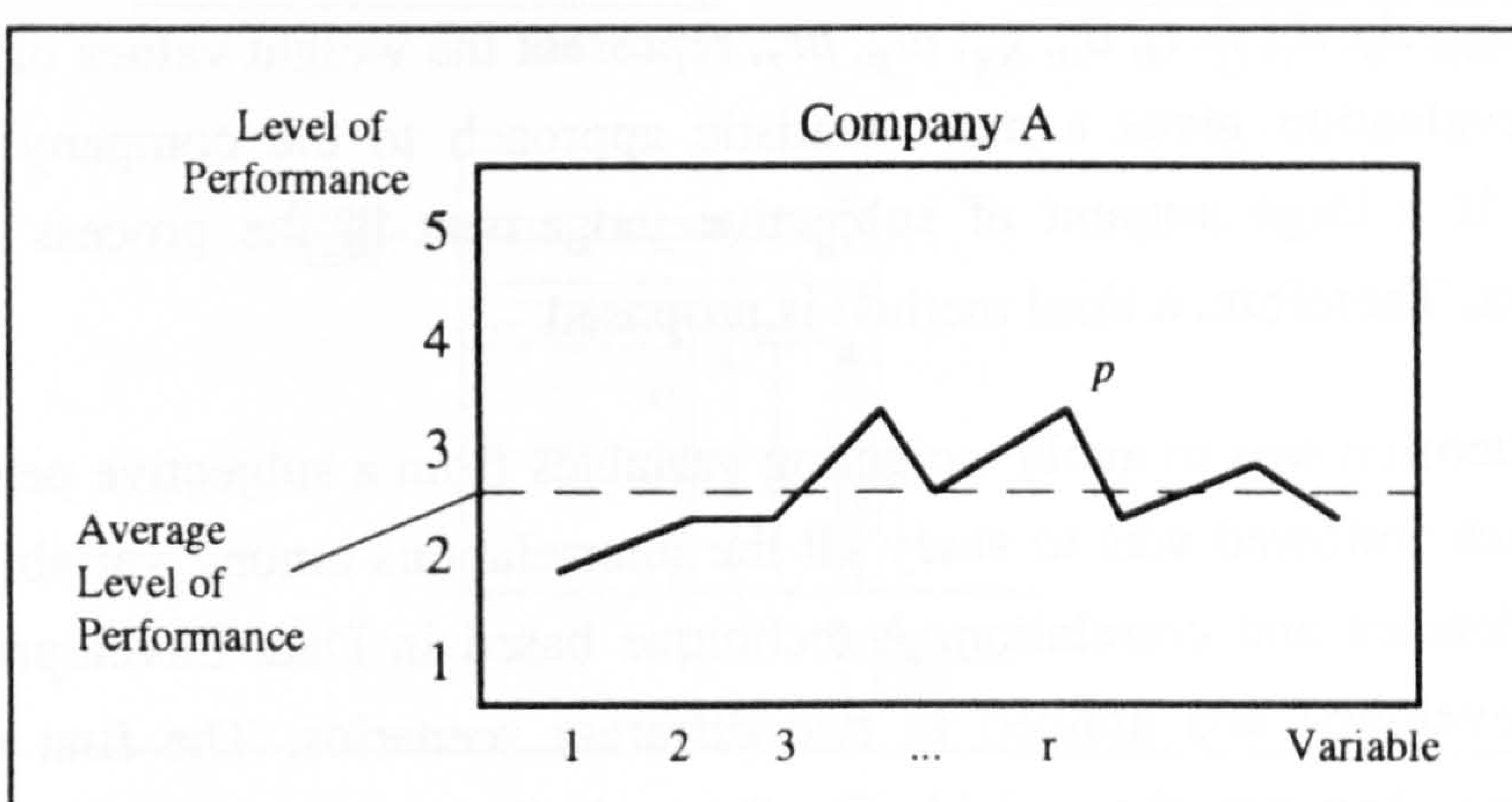

Figure 16 - Average Level of Performance

From Figure 16 it is possible to see graphically the profile of a certain company. The profile *p* represents the company performance, and low performance variables can be identified. The mean value of all the variables give the Average Level of Performance (ALP) of a company. ALP is the figure proposed as a "unit of leanness".

In this research, three different ways to evaluate the ALP have been studied:

1. In a first stage, it can be evaluated as a simple average between all the variables. Every variable has the same importance and the ALP is given by:

$$ALP = \frac{\sum Q_q + \sum D_d + \sum C_c + \sum F_f + \sum T_t + \sum A_a + \sum G_g + \sum PT_p + \sum PR_r}{\text{Total number of variables}}$$

where Q_q, D_d, C_c, F_f, T_s, A_a, G_g, PT_p, PR_r, represent the values of the variables under consideration. This evaluation gives a first approach to the company performance.

2. In a second approach, the expertise and experience can be used to weight the different variables. In Chapter 4.2 procedures for weighting variables are proposed. In this case, each variable has a specific weight in accordance with the importance that it was attributed to that variable. The ALP is given by:

$$ALP = \frac{\sum q_q Q_q + \sum d_d D_d + \sum c_c C_c + \sum f_f F_f + \sum t_t T_t + \sum a_a A_a + \sum g_g G_g + \sum pt_p PT_p + \sum pr_r PR_r}{\text{Total number of variables}}$$

where q_q, d_d, d_c, f_f, t_s, a_a, g_g, pt_p, pr_r, represent the weight values of the variables. This evaluation gives a more realistic approach to the company performance. There is a large amount of subjective judgement in the process of attributing weights. Therefore, a third method is proposed.

3. The intention was to avoid weighting variables from a subjective perspective. The approach followed was to study all the interrelations among variables to identify dependencies and correlation. A technique based in Data Envelopment Analysis was developed and applied in two different scenarios. The first considers the efficiency between the variable Quality and all the others. The second considers the relationships between the variable (Quality/Input$_i$) and all other variables (Variable/Input$_i$) that are significantly correlated. This approach allows the evaluation of a significant set of efficiencies, without weighting the variables. The final treatment of efficiencies give the ALP. The mathematical formulation of this case is presented in Chapter 4.2.3, and the results from its application are presented in Chapter 5.3.

3.4.4. Establishment of relationships between indicators

The last approach in the previous section was validated with a large amount of data from a number of textile companies. In a first stage, 324 companies have provided data via a questionnaire. In a follow-up phase 30 companies were selected and studied, providing useful and detailed information. To select the model variables, the data was analysed from different perspectives (Chapter 4 presents the methodologies used and Chapter 5 presents the results).

The data collected in the 30 companies allowed investigation of the relationships between variables and, in particular, between objective and subjective indicators. Figure 17 illustrates some of the relationships established.

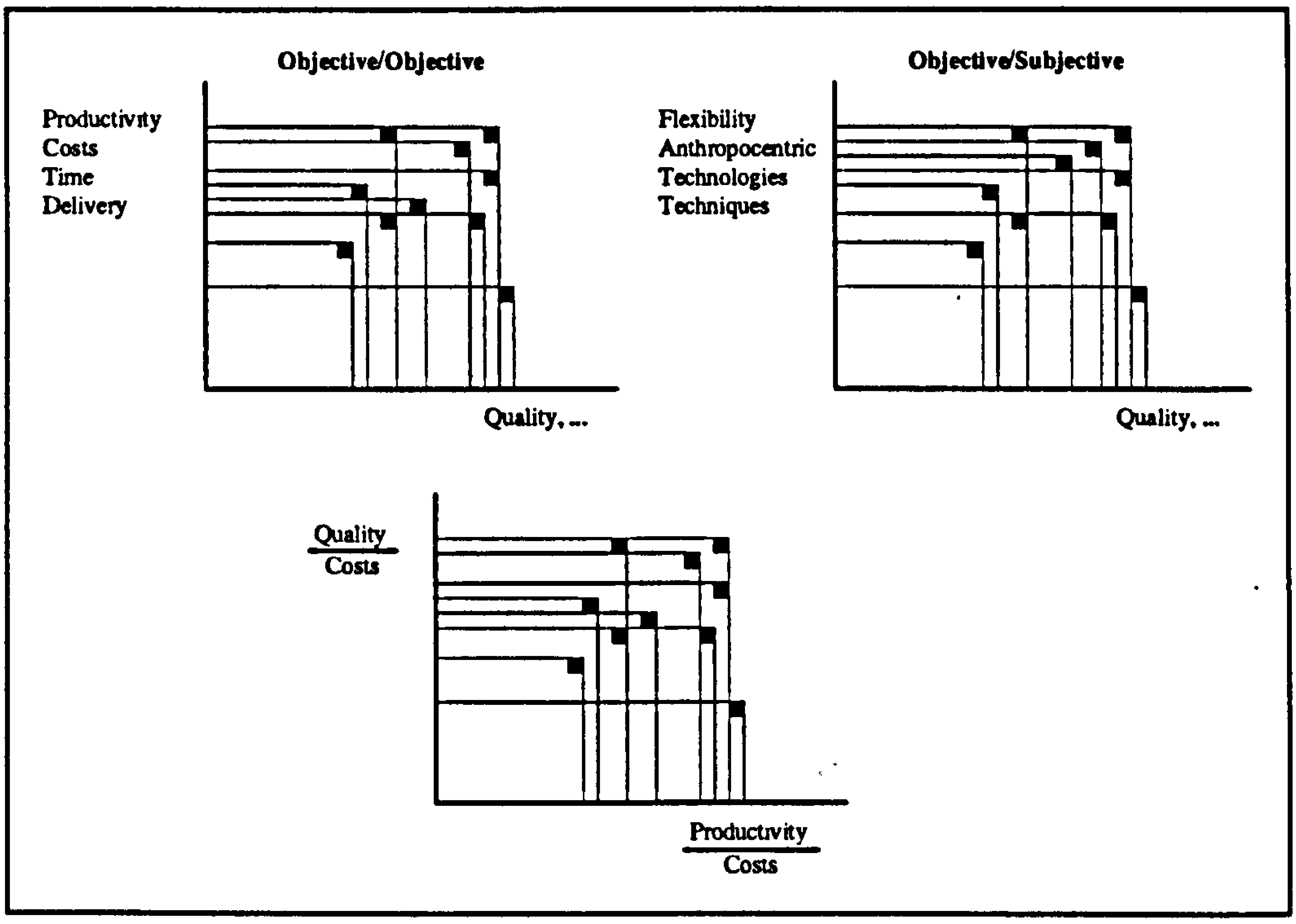

Figure 17 - Relationships between variables

This analysis allowed the selection of the final model variables and irrespective indicators used throughout the research. Table 9 shows the final model variables. In this table, the first column represents the model variables, the second column represents the indicators, and the third column represents the measured units. Where there is a "1-5" it means that it is related to a subjective indicator, which assessment gives a performance level between 1 and 5.

Table 9 - Model variables

Quality	Q1	Quality Assurance System	1-5
	Q2	Material scrap	% of defects
	Q3	Failure costs	% of turnover
	Q4	Quality costs	% of turnover
Delivery	D1	Timeliness of delivery	Past due orders/total no. of orders
	D2	Delivery lead time	No. of days to deliver
	D3	Average lateness of delivery	Days
Cost	C1	Raw material in warehouse	% of total costs
	C2	Work-in-process	% of total costs
	C3	Value Added per employee	Number
	C4	Production costs	Number
Flexibility	F1	Design flexibility	1-5
	F2	Production flexibility	1-5
	F3	Materials flexibility	1-5
	F4	People flexibility	1-5
Time	T1	Cycle time	Days
	T2	Setup time (average)	Minutes
	T3	Time to introduce new products	Days
	T4	Waste time (in terms of production capacity)	%
	T5	Materials residence in warehousing	Days
Anthropocentric	A1	Motivation	1-5
	A2	Communication	1-5
	A3	Training	1-5
	A4	Working conditions	1-5
	A5	Absenteeism	% of working days
Innovation	I1	No. of new products launched/year	Number
Technologies	G1	CAD/CAM	1-5
	G2	Robotics/automation	1-5
	G3	Materials handling	1-5
	G4	Warehousing	1-5
	G5	CIM/integration	1-5
	G6	Equipment	1-5
Techniques	PT1	Group Technology	1-5
	PT2	Just-in-time	1-5
	PT3	MRP	1-5
	PT4	Inventory management	1-5
	PT5	Work measurement (study)	1-5
	PT6	Layout design	1-5
	PT7	Maintenance management	1-5
Productivity	PR	Output rate/employee	Meters of fabric (wool/cotton), Parts (knitting/clothing)

3.4.5. Designing optimal performance

The proposed model for Lean Manufacturing provides the company with a structured set of performance indicators. This new performance measurement system allows the company to know where it stands towards Lean Manufacturing and its best competitors. It was designed to be used by quality managers to assess their company performance from a Lean perspective, and not only from a traditional Quality Assurance perspective. It aims at being a powerful tool for continuous improvement. As such it should provide the design of a meaningful set of improvement projects, to achieve an optimal performance. This implies the natural change from a static approach (as described before) to a dynamic one, where manufacturing practices must be continuously improved with a number of different inputs (Figure 18).

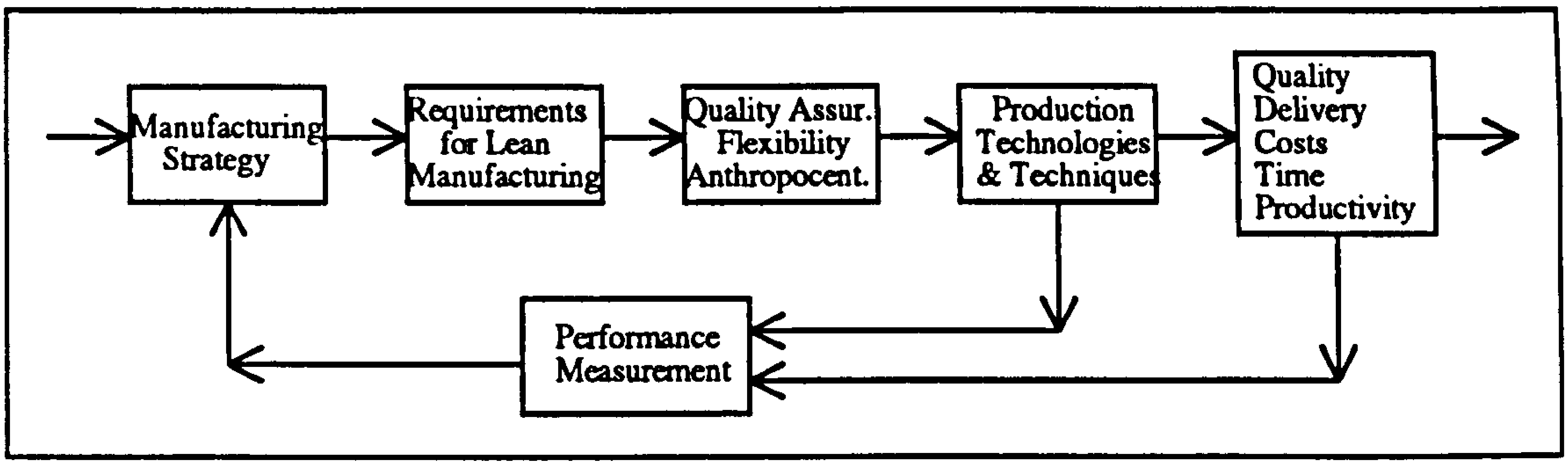

Figure 18 - Dynamic modelling

The model was designed to provide also a certain level of decision support as its results are given in a prioritised order (see Table 36). This fact allows the company to update its strategy and focus on the model variables with lower performance.

The research also approached the use of operational research techniques to find optimal performance. A brief description of the problem is presented. The objective is to maximise an overall performance objective function (ALP), subjected to some constrains.

Maximise:

$$ALP = \sum Q_q + \sum D_d + \sum C_c + \sum F_f + \sum T_t + \sum A_a + \sum G_g + \sum PT_p + \sum PR_r$$

or

Maximise: $$ALP = \sum_{k=1}^{r} a_k T_k$$

Subject to conditions of: Quality
Delivery
Cost
Time
Productivity

Where: $T_k = \begin{cases} 1 & \text{if variable k is selected} \\ 0 & \text{otherwise} \end{cases}$

$a_k =$ performance of variable k

$r =$ number of possible variables

When the performance objective function is maximised, the better company profile will be achieved.

The selection of the constraints is a complex process and depends on the strategic objectives of the company. In a different perspective, Sumanth [SUM84] and Foong & Hoang [FOO91] have approached this problem. Sumanth developed a model to optimise productivity, based in improving technology. He used a similar objective function and four constraints: maximum available funds, maximum allowable payback period, maximum allowable installation time, and minimum acceptable savings. It did not have success because some of these constraints require a rigid discipline and meaningful data. In addition, it is an outdated model as it is mainly based in financial measures and the trends to use non-financial measures are not addressed. Foong & Hoang proposed operational research techniques to find optimal performance for CIM. However, they only speculated about the usefulness of the technique. They considered, as a basic assumption, that the final aim of any business is to maximise profit, through the optimum utilisation of its assets and business strategy. They proposed six constraints: quality, cost, productivity, lead time, inventory, and flexibility. They concluded that there was no confidence on the mathematical equations established, and there was no evidence that they could be solved either.

This investigation into operational research techniques concludes that the intangible character of the constraints make it difficult to use these techniques.

3.4.6. Integration

The model proposed for assessing company performance towards Lean Manufacturing can be better exploited if it is integrated in the global information system of the company (Figure 19). The advantages are that the output variables can be measured automatically. Input variables must be measured periodically by internal or external experts. Its results must be inputted also in the company information system. Final results can be obtained periodically and can be displayed in different levels of aggregation for each user.

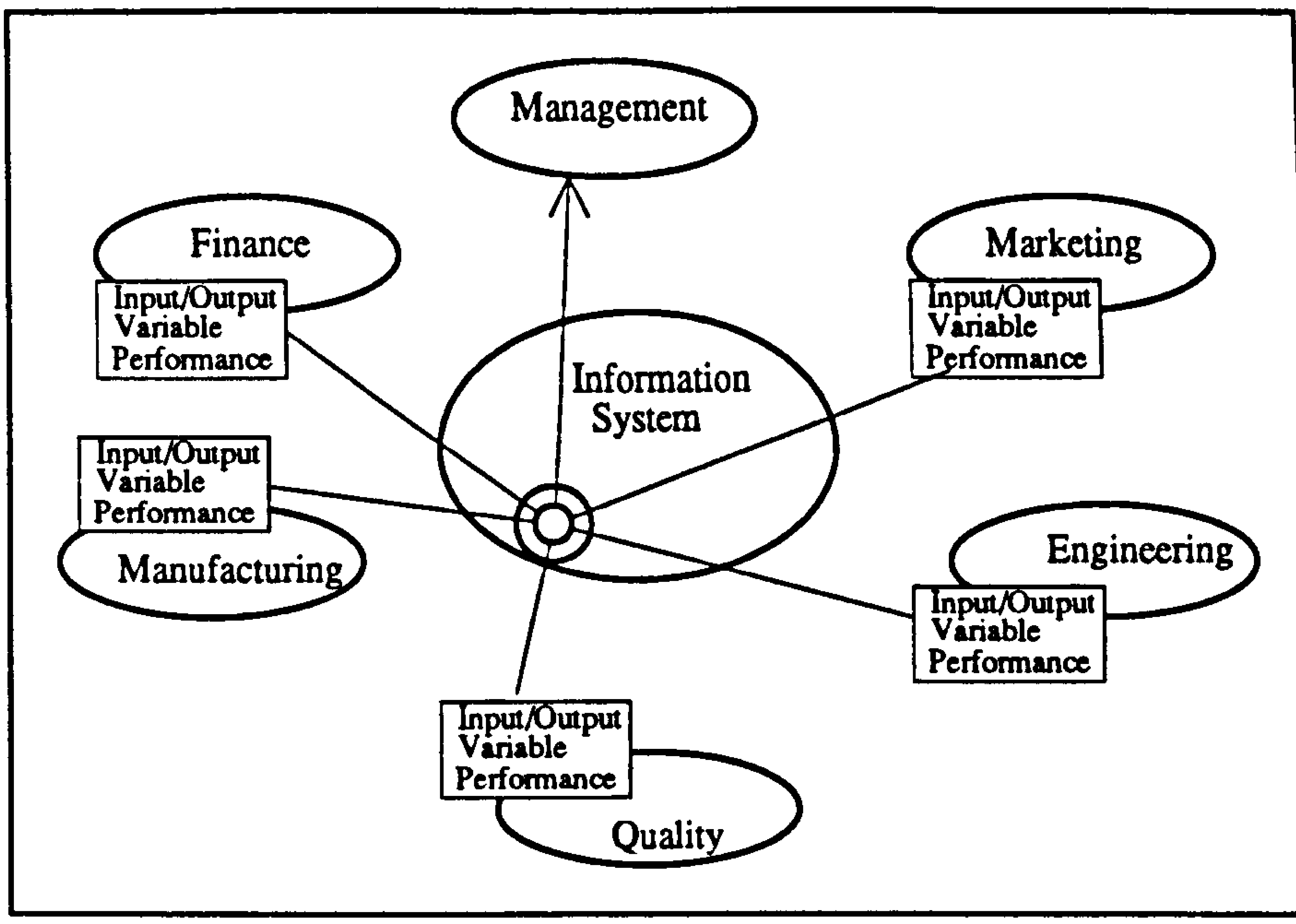

Figure 19 - Model integration in the company information system

After some time of implementation it is possible to create historical data base, and to analyse the company performance evolution. Comparing performance in the same company over time is a way to see its evolution and to find new ways to improve the processes. It is an important tool to management. However, changes in the environment can occur and special attention must be paid when there are changes in the level of economic activity, in technology, or in the market.

4. METHODOLOGIES AND TECHNIQUES

This chapter presents main methodologies and techniques developed for the modelling process. It includes questionnaires and audits design, and the procedures used for selecting and weighting performance measures.

4.1. Presentation of used methodologies

4.1.1. Approaching the situation

The success of this research depended on a good understanding of the industry. It was necessary to identify and to understand the problems and concerns of the companies to be able to develop a methodology to assess its performance. For this purpose, an evaluation and characterisation of the level of Organisation for Quality in the most representative textile companies was undertaken. Postal questionnaires, in-company diagnosis and quality audits were used.

A first diagnosis questionnaire was designed and it was sent to a pilot group of 250 textile companies. All of them were associates of the Textile Technological Centre. Seventy companies (30%) responded. It was considered a satisfactory rate of responses. From an analysis of this survey we identified four major sub-sectors (wool, cotton, knitting and clothing). The classification of the responses in sub-sectors brought some problems because each sub-sector had particular characteristics. In addition, the results per sub-sector (in terms of the total number of companies) were considered not representative of the total company population. In a second phase, this questionnaire was reviewed and it was sent to the universe of the textile industry. Based on official statistics there are about 1700 textile and clothing companies. Three hundred of them are very small (mainly in the clothing sub-sector), so the questionnaire was sent to 1400 companies. It was difficult to arrange the contacts of all these companies. For this purpose I had the help of the Textile Technological Centre and eight other Associations of Textile Industry in Portugal.

The amount of data that was received from questionnaires implied the programming of a data base to facilitate the analysis of the results. The treatment of these questionnaires gave a general overview of the industry. It also allowed me to select a representative sample of companies for more in-depth work. In these pre classified and targetted companies detailed and precise data was collected. For this purpose an extensive check list was prepared (see Annexes 3, 4, 5, and 6). It involved an analysis of technological features, production techniques, support technologies, information systems, indicators of company performance, organisation for quality, level of training and education, quality motivation, quality systems, reference standards, improvement projects, SPC, complaints, quality costs, etc..

The in-company work was based in the quality audit techniques to assess quality systems and the quality assurance standards were used as reference documents. The data collected was analysed and it provided the selection of the model variables of Lean Manufacturing. In addition, it provided also the input for a discussion about the implications of total quality systems in the implementation and management of new technologies and production techniques, under a Lean Manufacturing perspective.

4.1.2. Questionnaire structure

The questionnaire was structured in three parts: 1. to determine general information about the companies, namely, their main activities, size and markets; 2. to determine their main obstacles, priorities and preferred improvement means; 3. to determine existing quality practices, namely, awareness for quality, main indicators of product quality, organisation for quality, existence of a documented quality system and quality manual, level of inspection and calibration of test equipment and evaluation of quality costs.

The use of questionnaires is a suitable method to collect large amounts of data. However, several inherent weaknesses have been identified and these must be recognised when reading and interpreting the results presented in Chapter 5. The following factors have been considered throughout the design of the research, and in particular the use of the postal questionnaire:

- No sample can be said to be completely random because only people who are interested in the questionnaire will answer it,
- Respondents will tend to answer questions in a manner which will show them in the best possible light,

- The necessarily brief nature of the questionnaire does not facilitate the exploration of the attitudes involved in the development of quality systems,
- Open questions tend to have a low response rate.

4.1.3. Checklists structure

In my methodology auditing plays a vital role in company performance assessment. It is via auditing that it is possible to evaluate the input variables for the lean model. The scope of auditing must involve all the functions of a company. Plats [PLA90] shares this opinion. He identified three types of audits, namely:

- *Compliance audits* - used to determine whether actions have been in accordance with internal controls and procedures and with applicable external laws, regulations and practices,
- *Efficiency audits* - used to determine whether resources are being utilised as optimally as is practical (the ratio of inputs/outputs),
- *Effectiveness audits* - used to determine whether resources are being used to proper effect (the relationship of outputs to the desired goals of the business).

In addition, a literature review identified the following types of audits, usually carried out by managers, engineers or consultants:

- *Management audits* - cover all aspects of management, ranging from strategic issues to operational details,
- *Productivity audits* - concentrate on productivity,
- *Systems audits* - look at the formal systems within manufacturing, (ex: production control, process planning),
- *Quality audits* - related with the analysis of the quality system,
- *Specific audits* - look at one particular aspect of the manufacturing system (ex: energy, safety, materials handling)

Current audit approaches tend to concentrate on the effectiveness of existing systems, judging them mainly against the laid down procedures and the objectives of the particular sub-system under review. This situation reflects a lack of integrated methodologies which suggests that the effectiveness of this audit approach in identifying problems in the overall manufacturing system is not assured. In Annex 3 there is a general company audit checklist. It includes characteristics about products, production processes, technologies, production techniques, company strategy and competitive priorities.

My approach was to use quality audits as the starting point to integrate the results of different audits. This procedure allowed to quantify global company performance based on the results of those audits. Annex 4 is a checklist for assessment of quality systems. It is structured in four parts: 1. Organisation for quality, namely in what concerns quality function organisation and responsibilities; 2. Quality system, which includes quality policy, quality manual and procedures; 3. Quality control, which includes process control and sampling techniques, and; 4. Quality costs.

Annex 5 is a checklist for assessment of flexibility. It is structured to evaluate design flexibility, production flexibility, materials flexibility, and people flexibility. Annex 6 provides a checklist to assess the anthropocentric level of the company.

4.1.4. Quality assurance standards

Quality assurance requirements are much the same whatever the specific product or project. Quality system documentation encompasses the policy, the organisational structure, with the definition of authority and responsibilities, and also the quality assurance procedures related to the appropriate quality system requirements.

The ISO 9000 series is the international standard for quality systems. It tells suppliers and manufacturers what it requires for a quality-oriented management system. It does not set out unusual or special requirements with which only a few companies can or need comply, but is a practical standard for quality systems which can be used by all sectors of industry. The principles of ISO 9000 are applicable whether a company employs ten people or ten thousand. It identifies the basic principles and specifies the procedures and criteria to assure that either the goods leaving the factories or the services supplied meet each customer's requirements. ISO 9000 is quite separate from product or service performance and specification. The standard applies only to management systems which in themselves must be applied to producing a product or providing a service of the correct quality.

ISO 9000 recognises that the more complex and sophisticated products often require more extensive systems to control the production activities and hence to assess the quality. It is, therefore, effectively structured as five individual standards that make up the 9000 series (Table 10). ISO 9000 is the road map, providing guidelines for selection and use of 9001, 9002, 9003, and 9004.

Table 10 - ISO 9000 - Quality System Requirements

ISO 9001; 9002; 9003 Clause 4			
Clause 4 principal subclauses	9001	9002	9003
• Management Responsibility	A	B	C
• Quality system	A	A	B
• Contract review	A	A	-
• Design control	A	-	-
• Document control	A	A	B
• Purchasing	A	A	-
• Purchaser supplied product	A	A	-
• Product identification	A	A	B
• Process control	A	A	-
• Inspection and testing	A	A	B
• Measuring/test equipment	A	A	B
• Inspection and test status	A	A	B
• Control of non-conforming product	A	A	B
• Corrective action	A	A	-
• Handling, storage, packing and delivery	A	A	B
• Quality records	A	A	B
• Internal quality audits	A	B	-
• Training	A	B	C
• Servicing	A	-	-
• Statistical techniques	A	A	B

A - Full requirement, B - Less stringent than ISO 9001, C - Less stringent than ISO 9002

In this work the quality assurance standards were used only as reference tools. The work was not limited to the requirements included in the standards. These standards are well known in the industry. However, in modelling for Lean Manufacturing they must be complemented with other non-traditional quality standard requirements. This subject is addressed in Chapter 6.

The meaning of these quality system requirements is as follows:

1. ***Management responsibility***: the quality policy must be defined, documented and communicated to the whole organisation; the responsibility for quality must be clearly defined; the means and internal resources for activities verification must be available; a management representative must be appointed to assure that the quality system requirements are being observed; the management representative must review the system in a periodic basis to assure that it is always adequate and efficient.

2. ***Quality system***: the quality system should be established, documented and maintained to assure product or services conformance with the requirements. The documents of the quality system are the main evidences of its level of implementation, detailing how the policy on quality is implemented and executed. They include the quality manual, quality plans, quality procedures and technical instructions. The

quality manual should be distributed to, understand by, and used by people throughout the organisation. Procedures and resources to ensure that the quality manual is kept current must be well defined and apparent.

3. *Contract review*: the review and analysis of contracts confirm that the definition of requirements is correct, and assure that there is capacity to accomplish them. Usually, this requirement is mainly understood as related to Project (one-off item as in ships) or batch production (ex: paint). For line-flow processes, mass production (ex: refrigerators) or continuous production (ex: paper pulp), it is not considered appropriate as product is always the same and particular customer requirements can not be accepted (in Chapter 6 this requirement will be analysed in a different perspective).

4. *Design control*: this requires the preparation of procedures to control and verify the design of products and services, to assure that the specified requirements are accomplished.

5. *Documentation control*: this requires the preparation and maintenance of procedures for the control of documents through its reviewing, approval, issuing, distribution, amending, revising and substitution.

6. *Purchasing*: the purchased products must be in conformance with the specified requirements. It requires procedures for assessing sub-contractors and suppliers, clear and precise purchasing data (including quality assurance requirements, contractual liabilities, test reports and/or certificates package and transport requirements, items reception deadlines, etc.), and inspection of purchased products.

7. *Purchaser supplied product*: this requires procedures for the inspection, storage and maintenance of purchaser supplied items to be incorporated in the product.

8. *Product identification and traceability*: this requires procedures for product identification (individual or in batch) in all the production phases, expedition and installation.

9. *Process control*: this requires procedures to assure that production processes are executed under control. It includes adequate documentation, inspection and control of process and product characteristics, use of approved equipment and operational criteria. Process control addresses the completeness, utilisation, and effectiveness of quality specifications and instructional information to provide proper procedures for shop-floor personnel to follow in performing equipment changeover, part-processing operations, QC inspections, and corrective actions for internal part quality and system fail-

ures. It is essential in providing the shop with the information required to consistently perform work in a quality manner, supporting the reduction in process variability.

10. ***Inspection and testing***: this requires procedures for inspection and testing for the reception of goods, work in process, and finished products. They must include maintenance of records, and decisions on non-conforming product.

11. ***Inspection, measuring and test equipment***: this requires the establishment of a system of selection, control, calibration, and maintenance for all the equipment used in inspection and testing of products.

12. ***Inspection and test status***: this requires the labelling of the product, to show its conformity or non-conformity with the testing and inspections. It may be identified in any convenient way (from an inspection record only, to a labelled and segregated area). The key point is that the inspection status needs to be identified to those who have control over the item in question and who need to be aware.

13. ***Control of non-conforming product***: this requires the use of procedures to control non-conforming product, preventing its undue use. It includes its identification, segregation and evaluation.

14. ***Corrective action***: this requires procedures to investigate non-conformance causes, define preventive actions and control its effectiveness. Corrective action are essential to achieve control (avoiding that products, and processes of the quality system deviate from established parameters).

15. ***Handling, storage, packaging and delivery***: this requires procedures for handling, storage, packaging and delivery of products.

16. ***Quality records***: this requires the preparation of procedures for identification, collection, indexation, filing, storage, location, maintenance, and organisation of quality records. Quality records are necessary to show the effective operation of the quality system.

17. ***Internal quality audits***: this requires the practice of periodic audits to verify if the quality system activities are working properly and accomplish the established requirements. They allow detecting and correcting system discrepancies. Internal audits do not mean only an overall quality system effectiveness assessment (the audit plan shall encompasses it). The stress is also on audits of specific areas or functions.

18. *Training*: this requires procedures to identify the training needs, and subsequently to provide for the training of all personnel performing activities affecting quality.

19. *Servicing*: procedures are required when servicing is specified in the contract. The standards are made from the point of view of large purchasers. But from the point of view of the quality system owner it is also appropriate to document existing activities.

20. *Statistical techniques*: this requires the identification of correct methods (based in standards or technical documents) for verifying the acceptability of process capability and product/service characteristics. However, they can be used in other applications from reliability studies to reduction variation.

The methodology followed these requirements, but it was complemented with the checklists presented in Annexes 3, 4, 5, and 6. To assess each of the factors in the quality system audits, an evaluation and scoring system was developed. Table 11 show the quality system evaluation and the definition of scoring for quality systems audits.

Table 11 - Definition of scoring for Quality Systems Audits

Systems and/or procedures	Evaluation	Performance
Well defined and complete Concise and well documented Formally reviewed, and updated (possibly leading edge)	EXCELLENT (5)	Well understood and well executed Complete records (history) of adherence and compliance (Execution is a "way of life")
Adequately defined and complete Satisfactorily documented Informally reviewed, and updated (no deficiencies)	VERY GOOD (4)	Generally understood and well executed Satisfactory history of adherence and compliance (Execution is a "requirement of the job")
Mostly defined and complete Marginally documented (minor deficiencies)	GOOD (3)	Mostly understood and followed Satisfactory performance, adherence and compliance (Occasional omissions)
Marginally defined and complete Little documentation (numerous minor deficiencies)	FAIR (2)	Partially understood Performance, adherence and compliance requires some improvement (Frequent omissions)
Poorly defined and incomplete, but potential improvement exists (major deficiencies)	POOR (1)	Marginally understood Performance, adherence and compliance requires significant improvement (Very frequent omissions)
Not defined (no concrete plans for implementation)	FAILURE (0)	Not in place

4.1.5. Particularities of different companies

Although all the companies included were in the same industry, they represented different sub-sectors: wool and cotton (spinning and weaving), knitting and clothing. This situation led to a separate analysis for each sub-sector. However, as the purpose was modelling for Lean Manufacturing in all the textile and clothing industry, some transformations of the values of model variables were done. Table 12 shows the transformed values of the model variables. Notice that, after this transformation, all the variables have a value between 1 and 5 (1 means low performance and 5 means high performance).

Table 12 - Model variables transformation

	Material scrap	Failure costs	Timeliness of delivery	Delivery lead time	Average lateness of delivery	Raw material in warehouse
5	0 - 4	0 - 4	0 - 4	0 - 19	0	0 - 20
4	5 - 9	5 - 9	5 - 9	20 - 39	0 - 3	21 - 30
3	14 - 14	10 - 14	10 - 14	40 - 59	4 - 6	31 - 35
2	15 - 19	15 - 19	15 - 19	60 - 79	7 - 9	35 - 40
1	+ 20	+ 20	+ 20	+ 80	+ 10	+40
	Work-in-process	**Value Added per employee**	**Production costs per employee**	**Cycle time**	**Setup time**	**Time to introduce new prod.**
5	0 - 2	+ 2800	- 4400	0 - 9	0 - 0.5	0 - 30
4	3 - 5	2600 - 2799	4400 - 4599	10 - 19	0.6 - 1.0	31 - 60
3	6 - 8	2400 - 2599	4600 - 4799	20 - 29	1.1 - 1.5	61 - 90
2	9 - 11	2200 - 2399	4800 - 4999	30 - 39	1.6 - 2.0	91 - 120
1	+ 12	- 2200	+ 5000	+ 40	+ 2.0	+ 120
	Waste time	**Materials in warehouse**	**Absenteeism**	**No. of new products**	**Productivity (wool/cotton)**	**Productivity (knitt./clothing)**
5	0 - 5	0 - 15	0 - 2	+ 40	+ 2500	+ 4500
4	6 - 10	16 - 30	3 - 5	30 - 39	2301 - 2500	4301 - 4500
3	11 - 20	31 - 45	6 - 8	20 - 29	2101 - 2300	4101 - 4300
2	21 - 30	46 - 60	9 - 11	10 - 19	1901 - 2100	3901 - 4100
1	+ 30	+ 60	+ 12	0 - 9	- 1900	- 3900

4.1.6. Benchmarking

Benchmarking is the natural evolution process that follows an auditing activity. It is also the process of continually comparing a company's performance on critical customer requirements against that of the best in the industry (direct competitors) or class (companies recognised for their superiority in performing certain functions) to determine what should be improved [OWE92, VAZ92]. Establishing operating targets based on the best possible industry practices is a critical component in the success of every business. The objective is to meet or exceed the benchmarks by adopting or adapting the appropriate superior practices, regardless of the industry they are in.

Meeting this objective results in continuous improvements. Competitive benchmarking encourages innovation throughout an organisation. Rank Xerox defines benchmarking as [CAM89]:

> "The continuous process of measuring our products, services and business practices against the toughest competitors or those companies recognised as industry leaders".

Benchmarking is regarded as a goal-setting process. It is a means by which the practices needed to reach new goals are discovered and understood. Beyond the basic goal-setting objective of benchmarking the motivational worth of benchmarking also is significant. It empowers and encourages the organisation to move forward to realistic goals and change existing work practices which otherwise would have to be dictated. Ownership of and commitment to the benchmark is assured through agreement of the practices on which they are based. When a cross section of people in the organisation are involved in the benchmarking process, it focuses attention of the entire organisation on the correct business goals. Benchmarking has many similarities to performance measurement.

The basic benefits of benchmarking are derived from meeting customer requirements, establishing goals, measuring true productivity, becoming competitive, and ensuring that best industry practices are included in work processes [CAM89]. Table 13 illustrates the key reasons for benchmarking and contrasting results.

Table 13 - Key reasons for benchmarking [CAM89]

	Without benchmarking	With benchmarking
Defining requirements	• Based on history or gut feel • Perception • Low fit	• Market reality • Objective evaluation • High conformance
Establishing goals	• Lacking external focus • Reactive • Lagging industry	• Credible, unarguable • Proactive • Industry leading
Developing measures	• Pursuing pet projects • Strengths/weaknesses not understood • Route of least resistance	• Solving real problems • Understanding outputs • Based on best industry practices
Becoming competitive	• Internally focused • Evolutionary change • Low commitment	• Concrete understanding of competition • New ideas of proven practices • High commitment
Industry best practices	• Not invented here • Few solutions • Average of industry progress • Frantic catch-up activity	• Proactive search for change • Many options • Business practice breakthrough • Superior performance

Unfortunately, most organisations possess incomplete information about what is the best. Consequently, most innovations and improvement targets are set internally, based on past performance. The result is conservative plans and activities that are inadequate when compared to the rate of improvement necessary to remain successful.

In my methodology, modelling for Lean Manufacturing in the textile industry provides a benchmarking process where information about best performing companies is available. Any company that aspires a higher level of leanness can be compared with the best performing company if both use the model proposed.

4.2. Procedures of selecting and weighting performance measures

4.2.1. Analytic Hierarchy Process

Table 11 listed the variables of the model for Lean Manufacturing. It is not necessary for a company to utilise all those measures to evaluate its performance. In addition, some of those variables can be more important than others for a specific company. Consequently, priorities can be made explicit by weighting one performance criteria more than the others.

The Analytic Hierarchy Process (AHP) is a procedure of selecting and weighting the performance measures. It is a "multi criteria decision method that used hierarchy or network structures to represent a decision problem and then develops priorities for the alternatives based on the decision maker's judgements throughout the system" [SAA87]. We can utilise the AHP method to derive the relative weights of performance measures. Consequently, we can select the most important performance measures since the number of measures in a performance measurement system should be limited to a reasonable size.

Table 11 resulted from a first AHP analysis. Two main sets of performance issues were identified and developed (Figure 20). The designated Technological Performance includes the technologies themselves and the associated production techniques. In the other set under the designation of Environmental Performance, there are all the other non-technological and intangible variables that affect company competitiveness.

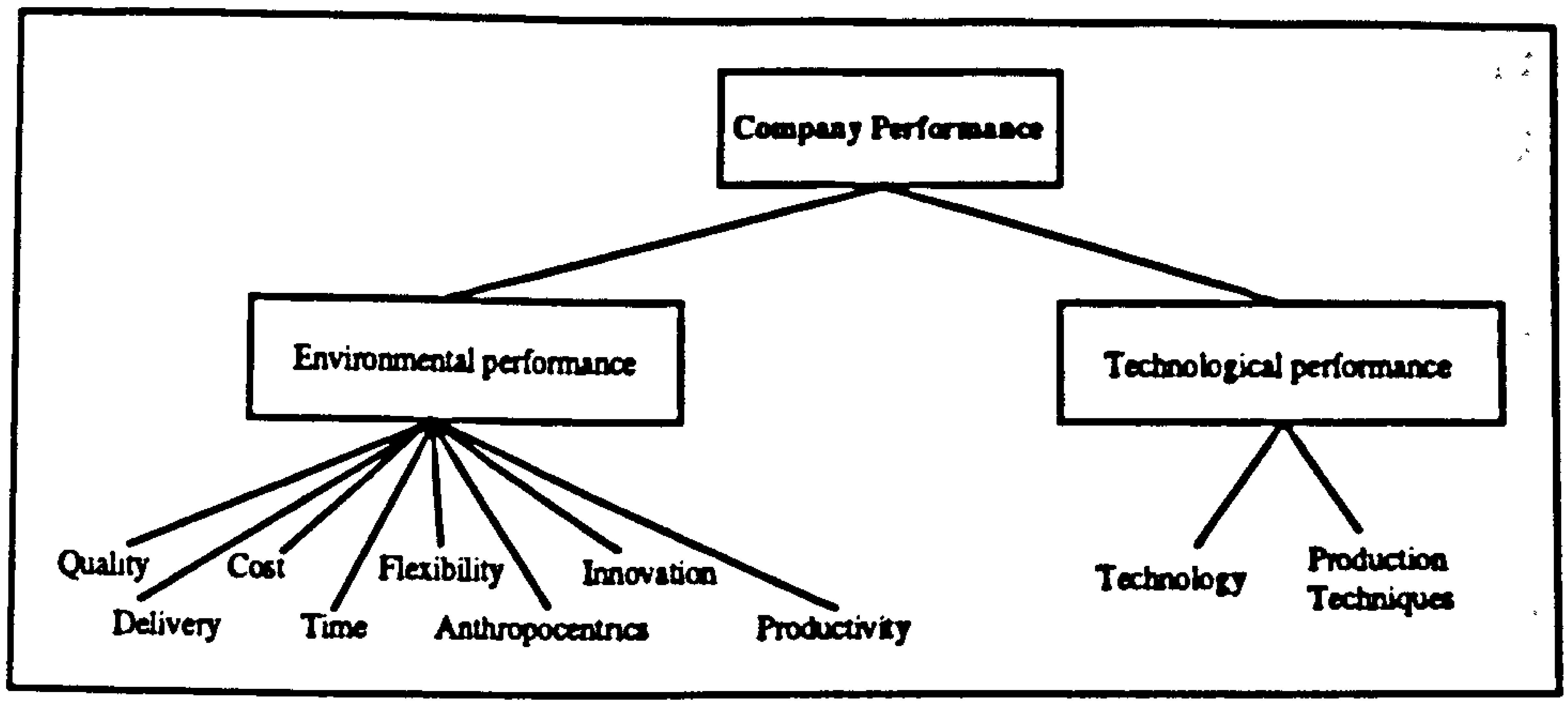

Figure 20 - AHP analysis

4.2.2. Case based system

To allocate weights to the model variables, a small survey was conducted after the audit process. Fifty people, including industrialists (40%), managers (40%) and academic and experts (20%) were asked to rank (by relative importance in a scale 0-100) the various variables proposed for the model. The main question addressed was: how important are the following factors for the success of your company? (a list of the factors was given). The results are summarised in Table 14. The answers distribution by variable demonstrate a high level of consensus between respondents.

Table 14 - Weighting model variables

Variables	Weight	Variables	Weight
Quality		Anthropocentrics	
Q1	0.93	A1	0.98
Q2	1.00	A2	0.72
Q3	1.00	A3	0.92
Q4	0.96	A4	0.94
Delivery		A5	1.00
D1	0.96	Innovation	
D2	0.94	I	0.83
D3	0.91	Technologies	
Cost		G1	0.81
C1	0.88	G2	0.96
C2	0.92	G3	0.87
C3	1.00	G4	0.79
C4	0.98	G5	0.74
Flexibility		G6	0.98
F1	0.75	Production techniques	
F2	0.88	PT1	0.81
F3	0.84	PT2	0.92
F4	0.97	PT3	0.95
Time		PT4	0.88
T1	0.93	PT5	0.98
T2	0.79	PT6	0.96
T3	0.94	PT7	0.98
T4	0.99	Productivity	
T5	0.89	PR	1.00

4.2.3. Data Envelopment Analysis

Another method used to analyse data, avoiding the direct use of weighting variables, was the Data Envelopment Analysis (DEA) method. DEA is a powerful tool for evaluating the performance of comparable organisational units. Charnes, Cooper and Rhodes [CHA78] used the term Data Envelopment Analysis to describe their approach to efficiency evaluation as a "method for advising data to prescribed theoretical requirements such as optimal production surfaces ...". DEA is a non-parametric assessment and it can be described in the following terms:

> "The efficiency measure of a Decision Making Unit is defined by its position relative to the frontier of best performance established mathematically by the ratio of weighted sum of outputs to weighted sum of inputs". [NOR91]

The entities responsible for committing inputs in pursuit of outputs are called decision-making units (DMU). Each DMU can be ranked relative to all others. Traditionally, DEA is a procedure for the measurement of efficiency in nonprofit contexts [WON90]. In DEA analysis, neither the output nor the input needs to be measured in financial terms. Since it was proposed in 1978, DEA has found its way into such areas as education, health services, local government, banking, petroleum and gas industry, airlines companies, and electric distribution. No references were found regarding its application in the textile industry or in the context of Lean Manufacturing. DEA is a linear programming-based technique for measuring the relative performance of organisational units where the presence of multiple inputs and outputs makes comparison difficult. It can be used to elaborate on the performance of individual units and to ascertain how the units can become more efficient.

There are two empirical approaches to the measurement of efficiency. The first is parametric (either stochastic or deterministic). Here, the form of the production function (the isoquant c in Figure 21) is either assumed to be known or is estimated statistically. The advantages of this approach are that any hypothesis can be tested with statistical rigour and that relationships between inputs and outputs follow known functional forms. However, in many cases there is no known functional form for the production function and it may be inappropriate to talk in terms of such a "production" function.

In the non-parametric approach with which we shall be concerned, no assumptions are made about the form of the production function. Instead, a best practice function built empirically from observed inputs and outputs is used. This will necessarily be piecewise linear and, as such, would be an approximation to the "true" function. Figure 21 shows observations for a number of similar units, A - J, where the axes represent input consumed per unit output produced. The efficiency "frontier" is designated by the lines joining D to B, B to G, and G to J; the frontier is assumed to extend parallel to the axes beyond D and J. Efficiency for point C is $\varepsilon_C = OQ/OC$. Efficiency for points on the isoquant line *c* is $\varepsilon = 1$. Norman & Stoker [NOR91] had demonstrated that the graphical efficiency measure for a specific point is equivalent to the value of the ratio of a weighted sum of its inputs where the weights are selected to maximise the value of the ratio subject to the value of the same weighted ratio of any other point outputs and inputs not exceeding 1.

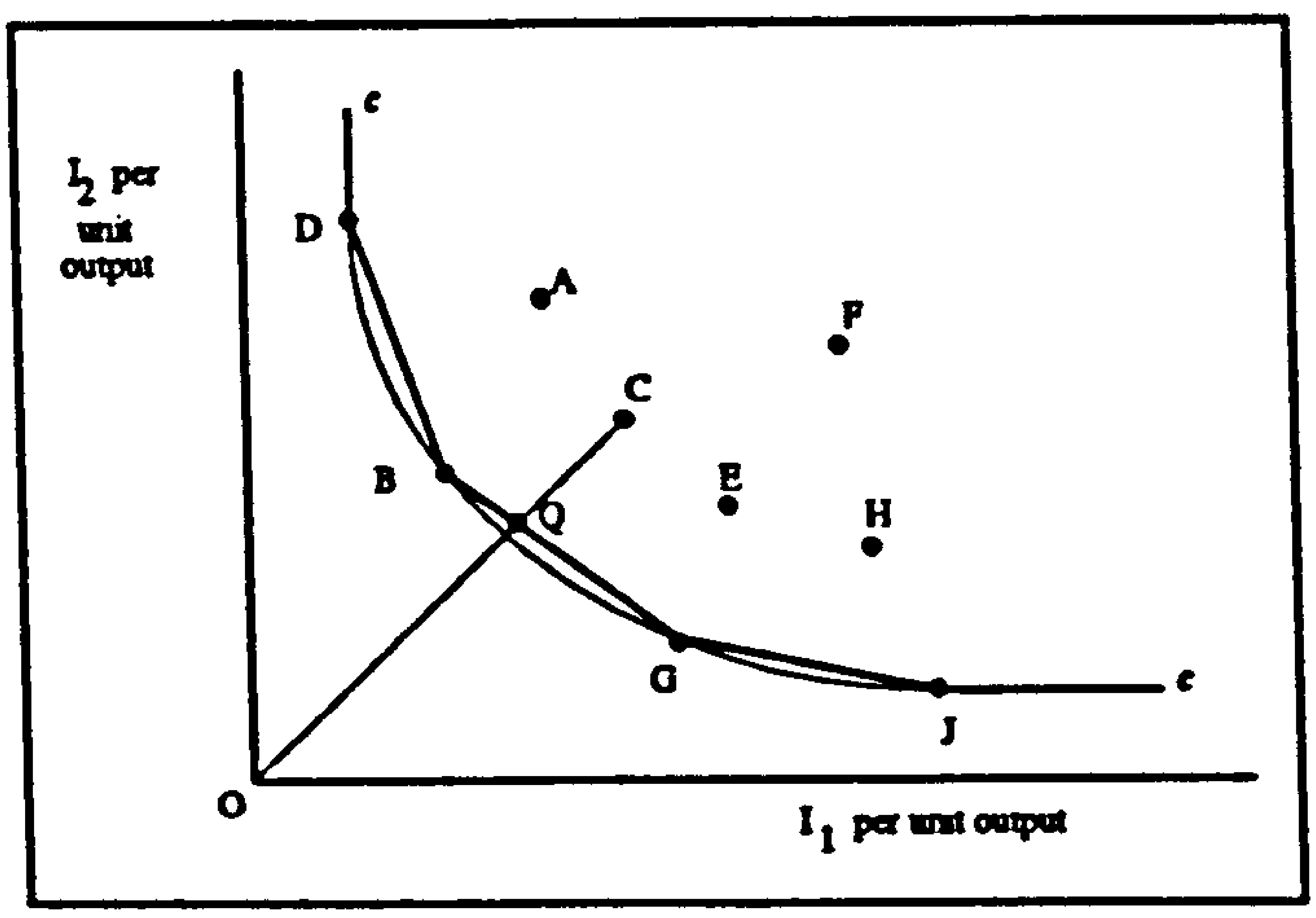

Figure 21 - Data envelopment analysis [NOR91]

The major objection to the frontier approach has been that the frontier itself is determined by the extreme observations of the data set; thus the definition of the frontier could be sensitive to errors or inconsistencies of data. A way to overcome this problem, is to fit a constrained frontier around the data according to some functional form (for example: least squares). In section 5.3.3 a constrained frontier was considered to envelope all the data points. The data envelopment analysis stems directly from the graphical process - the frontier envelops the other data points. In fact, the frontier is often referred to as the envelope.

The DEA model can be formulated as a linear traditional programme, which can be solved if it is transformed into an equivalent linear programme. Therefore, the mathematical formulation of DEA to compare the performance of n units with:

s outputs denoted by y_j, $\quad j = 1, \dots, s$

r inputs denoted by x_i, $\quad i = 1, \dots, r$

is to maximise the efficiency measure for unit O as follows:

$$\max \quad e_0 \quad = \quad \frac{\sum_{j=1}^{s} w_j y_{jo}}{\sum_{i=1}^{r} v_i x_{io}}$$

subject to:

$$\begin{aligned} \frac{\sum_{j=1}^{s} w_j y_{jm}}{\sum_{i=1}^{r} v_i x_{im}} &\leq 1; \quad m = 1,\dots,n \\ w_j &\geq 0; \quad j = 1,\dots,s \\ v_i &\geq 0; \quad i = 1,\dots,r \end{aligned}$$

Where the value of the ratio for unit O is less than 1, the subset of units whose ratio value is equal to 1 is the reference set for unit O.

This problem can be solved by a linear programming formulation. The denominator of the function to be maximised, i.e. the weighted sum of inputs, can be constrained to 1. Since it is possible in the above formulation to multiply all v_i and all w_j by a constant whilst leaving all the ratios unchanged, there is no loss of generality in introducing this additional constraint. The problem can then be expressed as the following linear programming:

$$\max \quad e_0 \quad = \quad \sum_{j=1}^{s} w_j \, y_{jo}$$

subject to:

$$\begin{aligned} \sum_{i=1}^{r} v_i x_{im} - \sum_{j=1}^{s} w_j y_{jm} &\geq 0; \quad m = 1,\dots,n \\ \sum_{i=1}^{r} v_i x_{io} &= 1 \\ w_j &\geq 0; \quad j = 1,\dots,s \\ v_i &\geq 0; \quad i = 1,\dots,r \end{aligned}$$

The theory of linear programming is outside the scope of this work, but I have provided an explanation of how the data envelopment analysis formulation can be used in my modelling process for Lean Manufacturing. This formulation is applied in section 5.3. A specific computer program was developed to assist the calculations presented in section 5.3.

5. RESULTS

This chapter presents the main results from the diagnosis questionnaires, audits and model application. The audit process seeks to validate data from the questionnaires and provide a deep understanding of the industry. Both gave input to the design of the model. Different scenarios are considered for the model application. A final analysis and discussion of results is carried out.

5.1. Results from the diagnosis questionnaire

5.1.1. Introduction

In a first step a questionnaire was designed and sent to a sample of two hundred and fifty companies. Data from 70 companies (30%) that answered the questionnaire was collected and analysed and some questionnaire adjustments were made. The percentage of answers was considered satisfactory, but it was necessary to adapt the questionnaire to some requirements of the model being developed. In addition, it was necessary to have a better representation of the industry in what concerns a higher number of companies, to have a better understanding of the industry. In the second step, the questionnaire was mailed to the universe of the industry, which accounts for some 1400 companies (official statistics). Companies with less then 20 employees were not considered. The process of getting responses from companies was very demanding and took more time than was expected. In some cases, namely those related to well known companies, it was necessary to establish supplementary contacts to get their responses.

The questionnaire was designed to evaluate in particular the level of organisation for quality, namely what concerns the quality management, quality system, quality control, quality costs and awareness for the quality function deployment.

Some comparisons were carried out having in mind the following aspects:

- the industrial sub-sector where the company belongs,
- the size of the company in terms of number of employees and turnover,

- the geographic situation of the company,
- the nationality of the company.

Companies were integrated in six size levels, regarding number of employees and turnover:

Employees		Turnover (millions PTES)	Company size
1.	less 50	less 50	small
2.	50 to 99	50 to 99	small/medium
3.	100 to 199	100 to 199	medium
4.	200 to 499	200 to 499	medium/large
5.	500 to 999	500 to 999	large
6.	more 1000	more 1000	very large

The principal objective of this approach was to find eventual differences between the six size company levels. Another objective was to provide criteria for the selection of a shorter sample of companies. Within this sample of companies, deeper diagnoses were carried out to complement and validate the questionnaire responses.

The initial analysis of questionnaires identified four main sub-sectors: wool sector, cotton sector, knitting sector and clothing sector (Figure 22). The study was led separately for each sub-sector and the size of the company was also considered. A significant number of the respondents were small companies (45%) - less than 100 employees - and medium companies (42%). Large companies (more than 500 employees) represented 13% of the respondents.

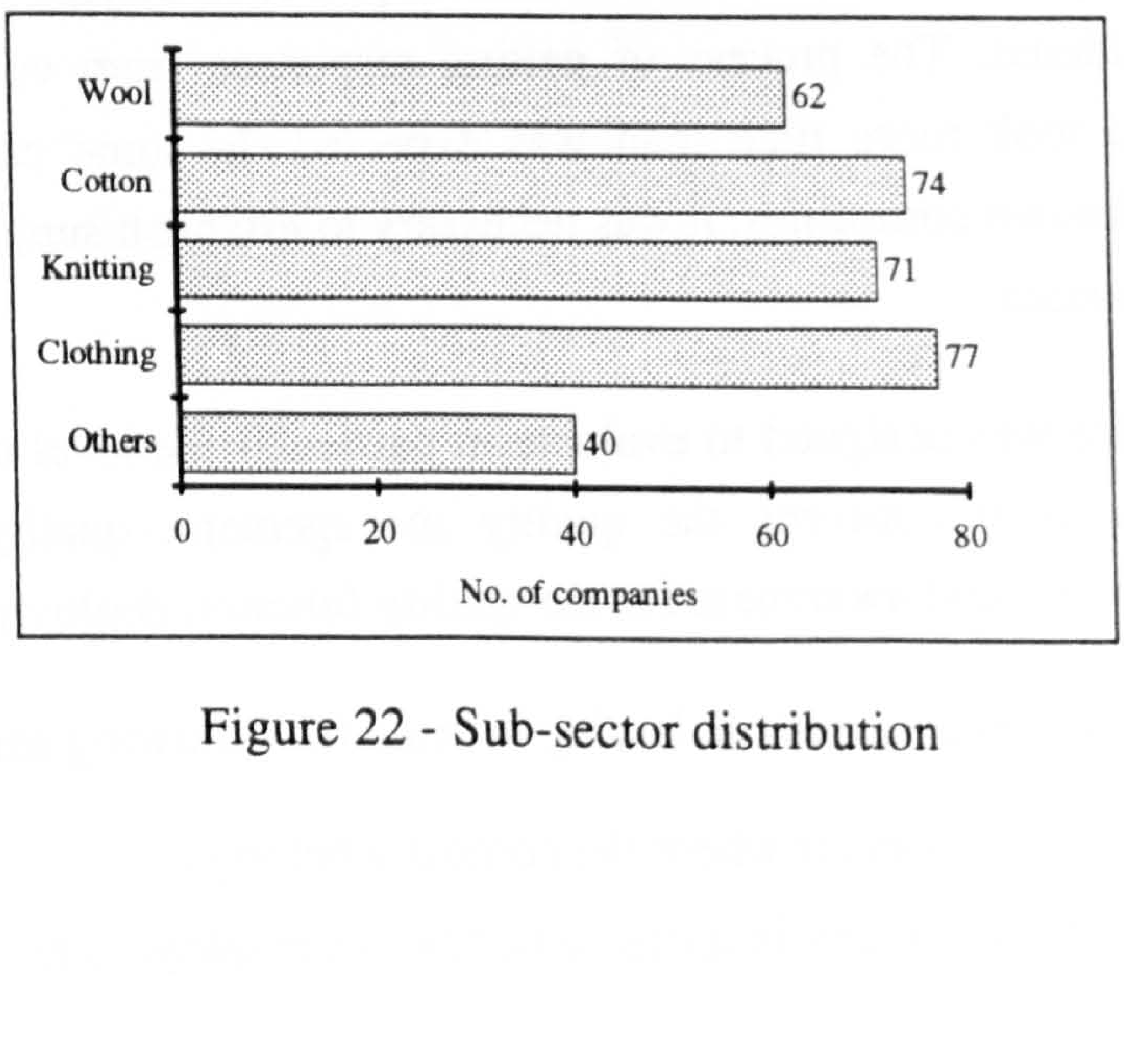

Figure 22 - Sub-sector distribution

5.1.2. Sample size analysis

The sample was analysed as a percentage of the total number of existing companies and the total number of employees in each sub-sector:

Table 15 - Sample size

	Number of Employees			Number of Companies		
	Official Statistics	Sample size	(%)	Official Statistics	Sample size	(%)
Wool	19775	13739	69	115	62	54
Cotton	69787	26693	38	315	74	24
Knitting	31864	8894	28	367	71	19
Clothing	52456	16821	32	497	77	16
Others	12691	5370	42	220	40	18
Total	185573	66147	36	1514	324	21

From Table 15 it is interesting to point out that the sample represented 36% of the total number of employees in the TCI, which can be considered a good value. As the sample represented 21% of the total number of companies, it means that the sample represented a set of companies that are slightly larger than the national average.

This industry is concentrated in the north of Portugal - 61% of the responses were from this area. Another important concentration is in the east centre where the wool sub-sector is mainly located, Figure 23.

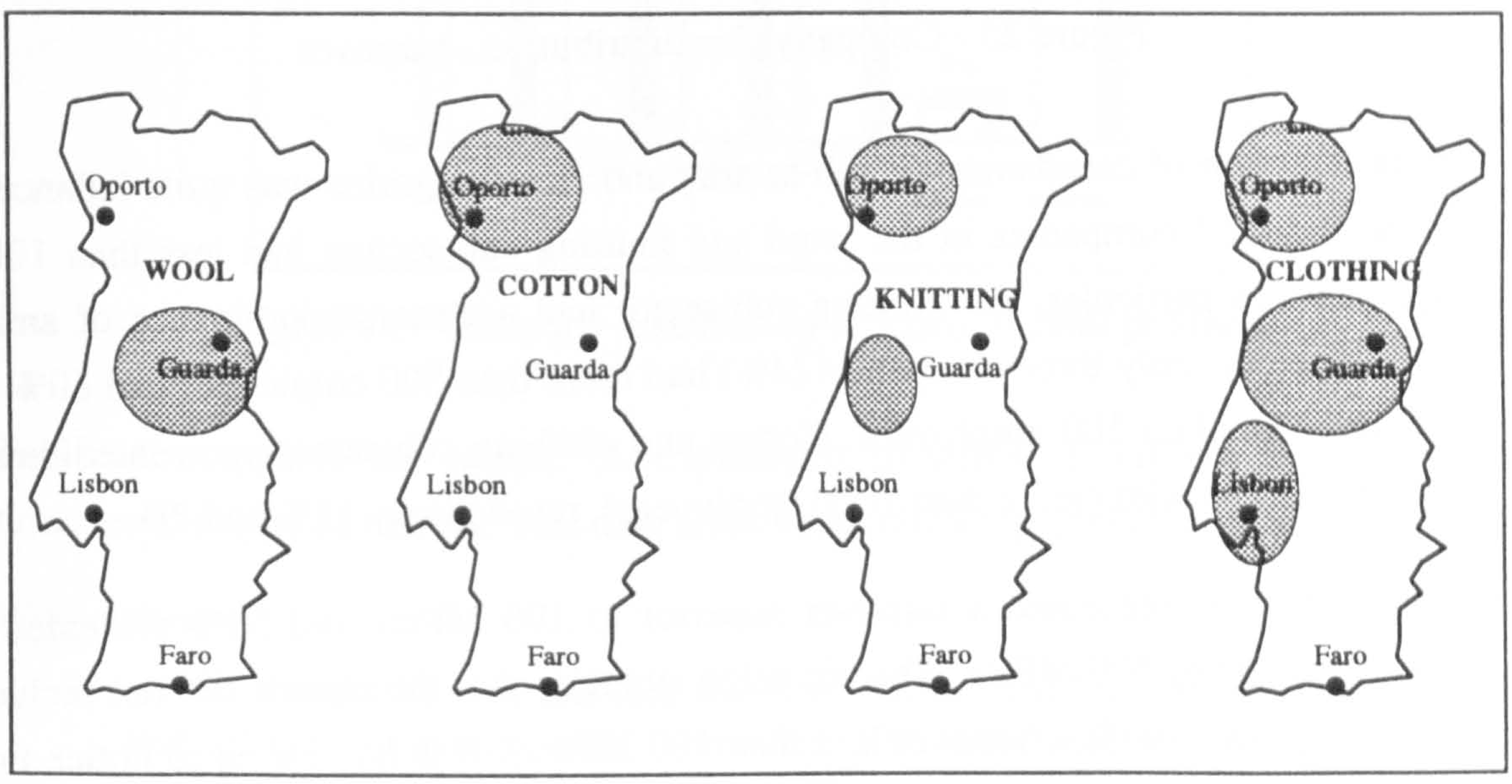

Figure 23 - Geographical distribution

In terms of dimensional indicators (number of employees and turnover) the sample of the inquired companies shows that wool and cotton companies are bigger than the others, Figure 24 and Figure 25.

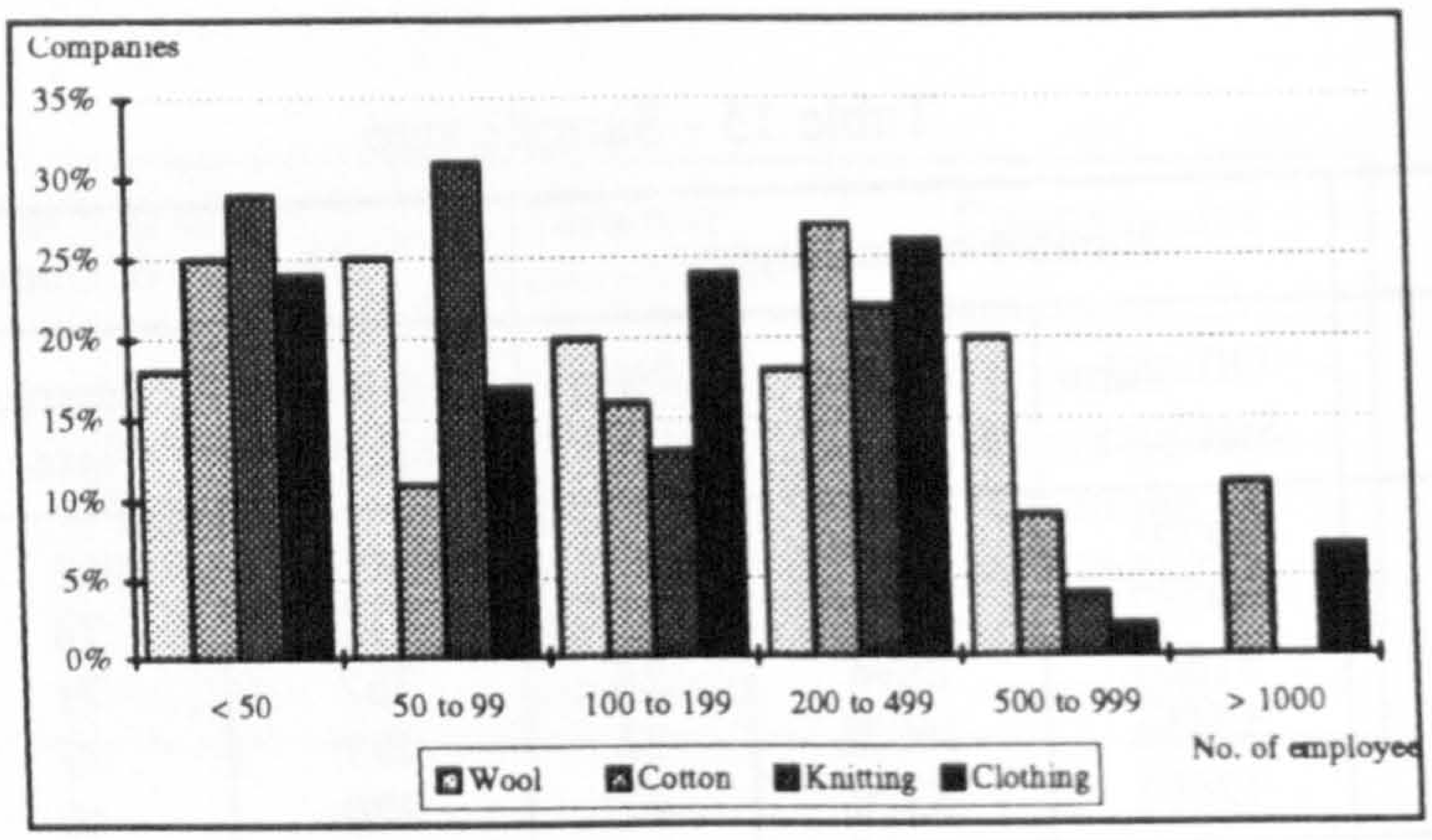

Figure 24 - Company size distribution - number of employees

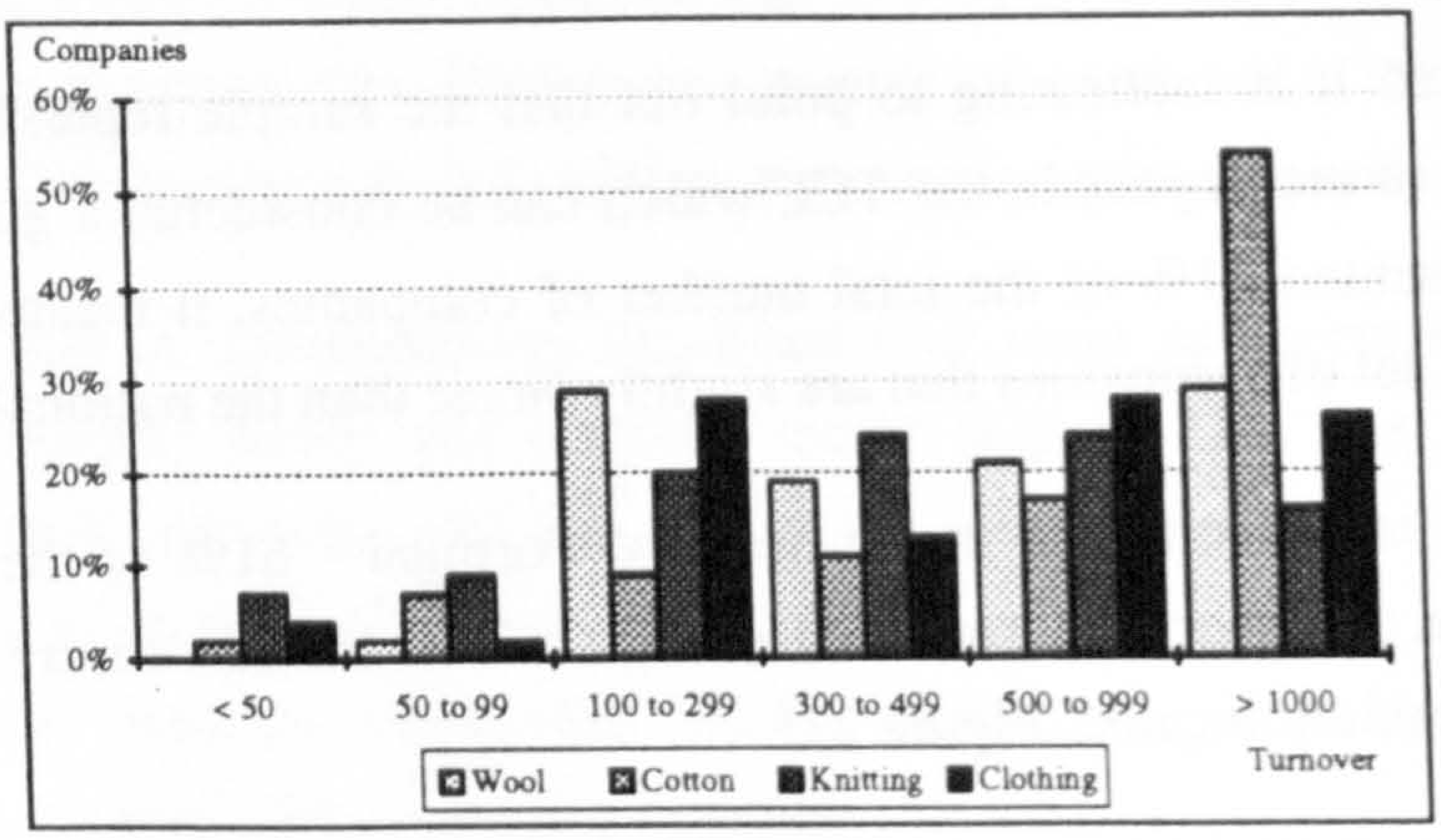

Figure 25 - Company size distribution - turnover

The distribution of companies by sub-sectors and size categories was quite balanced. All the inquired companies in the wool and knitting sub-sectors had less than 1000 employees. In particular, the knitting sub-sector had a clear predominance of small size companies: only three companies (4%) had more than 500 employees and 60% of them had less than 100 employees. Cotton and clothing sub-sectors presented some very large companies (more than 1000 employees), respectively 11% and 7%.

Most companies presented a turnover superior to 100 MPtes and 50% presented a value greater than 500 MPtes. This situation suggests that the sample did not include small companies (with a turnover less than 100 MPtes). It is interesting to notice that the knitting sub-sector presented the highest turnover per employee.

Of the respondents all the companies were private. In terms of capital share the scenario was the following:

- *Wool sub-sector* - one company had public capital (5%) and foreign capital (7%)
- *Cotton sub-sector* - one company had public capital (17%) and three companies had foreign capital (20%, 21%, 52%)
- *Knitting sub-sector* - two companies had foreign capital (40%, 100%)
- *Clothing sub-sector* - five companies had foreign capital (more than 85%)

Figure 26 shows the company distribution in terms of kind of final product. In the wool sub-sector most inquired companies were concerned with yarn (70%) and fabrics (57%) manufacture. Some of them also produced home textiles, clothing and technical textiles. In the cotton sub-sector most companies produced yarn, fabrics and home textiles. A reduced number also produced knitting, clothing and technical textiles. These sub-sectors can be considered as typical vertical sectors. In the knitting sub-sector most inquired companies produced knitting and a significant number produced clothing too. The clothing sub-sector included companies that produced shirts, trousers, suits, jackets and other general clothing. A reduced number produced also knitting goods.

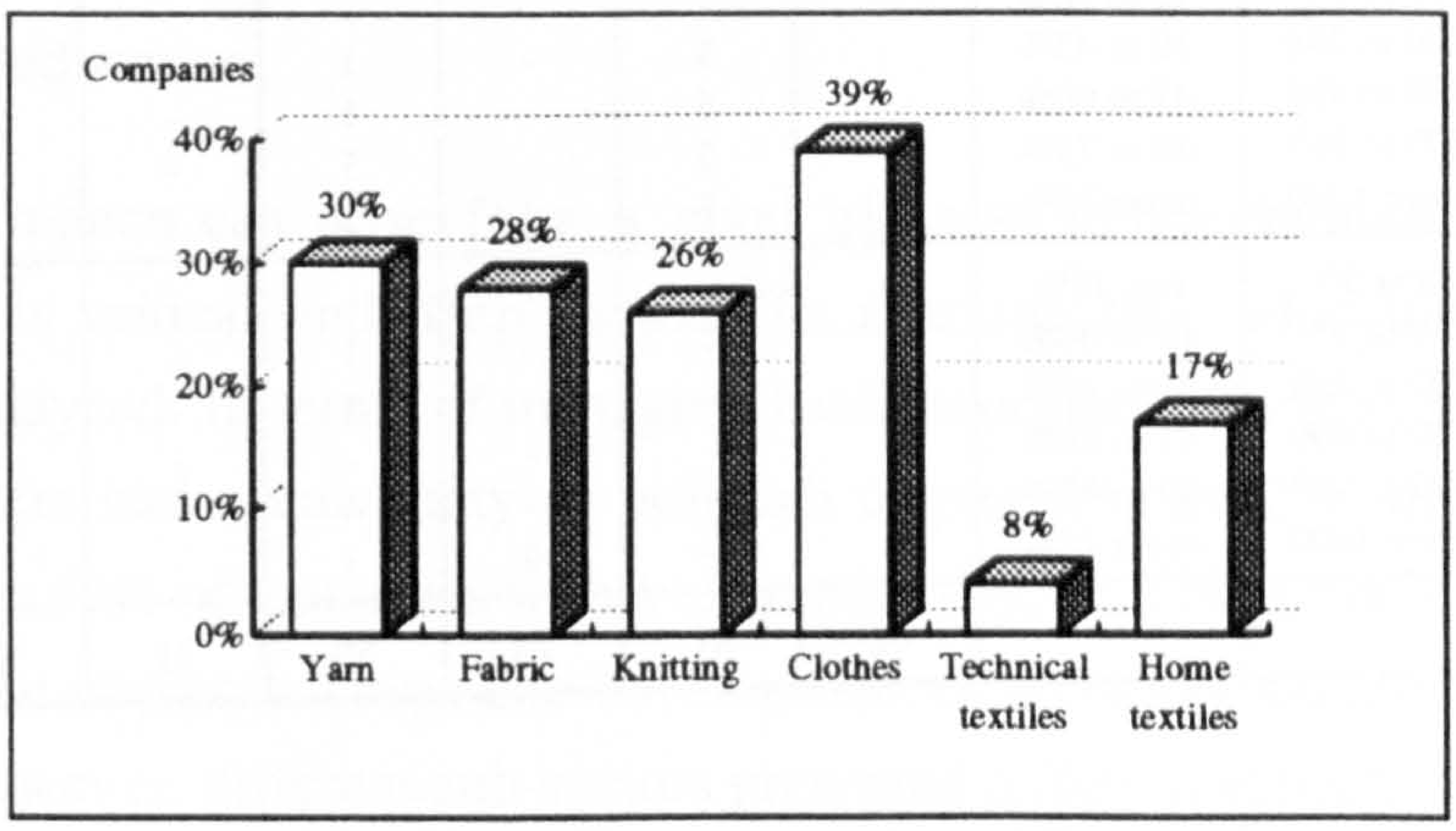

Figure 26 - Company distribution in terms of final products

Table 16 compares the sample of respondents in terms of number of employees, turnover and type of market. This data allows the following general comments:

Wool sub-sector:

- all the companies that sell less than 300 MPtes had less than 200 employees and all the companies with more than 500 employees sell more than 1000 MPtes. However, there are companies that sell more than 1000 MPtes and that belong to different size categories.

Table 16 - Characterisation of the sample of companies inquired

			Wool		Cotton		Knitting		Clothing	
No. of employees	Turnover (M PTES)	International market	Turn-over	Int. Market	Turn-over	Int. Market	Turn-over	Int. Market	Turn-over	Int. Market
less 50	less 50	less 15%	-	1	1	2	5	4	4	-
	50 to 99	15 to 30%	2	-	5	1	5	-	2	-
	100 to 299	30 to 45%	5	-	5	3	6	2	8	-
	300 to 499	45 to 60%	-	-	5	1	3	-	2	1
	500 to 999	60 to 75%	2	-	2	-	2	-	1	1
	more 1000	more 75%	1	-	-	-	-	6	1	13
50 to 99	less 50	less 15%	-	6	-	1	-	2	-	-
	50 to 99	15 to 30%	1	1	-	1	1	2	-	-
	100 to 299	30 to 45%	8	-	1	2	8	3	9	-
	300 to 499	45 to 60%	3	-	3	1	8	1	2	1
	500 to 999	60 to 75%	3	-	1	-	5	-	2	1
	more 1000	more 75%	-	-	3	-	-	12	-	11
100 to 199	less 50	less 15%	-	2	-	2	-	1	-	-
	50 to 99	15 to 30%	-	3	-	1	-	-	-	1
	100 to 299	30 to 45%	3	2	-	1	-	-	3	-
	300 to 499	45 to 60%	5	1	-	2	6	-	5	1
	500 to 999	60 to 75%	5	-	7	2	3	1	9	1
	more 1000	more 75%	-	-	4	-	-	6	1	10
200 to 499	less 50	less 15%	-	-	-	4	-	3	-	-
	50 to 99	15 to 30%	-	1	-	1	-	2	-	1
	100 to 299	30 to 45%	-	5	-	2	-	3	-	2
	300 to 499	45 to 60%	3	3	-	3	-	-	3	-
	500 to 999	60 to 75%	5	1	3	6	8	1	8	1
	more 1000	more 75%	4	2	17	4	8	6	10	12
500 to 999	less 50	less 15%	-	-	-	-	-	-	-	-
	50 to 99	15 to 30%	-	-	-	-	-	1	-	-
	100 to 299	30 to 45%	-	3	-	1	-	-	-	-
	300 to 499	45 to 60%	-	5	-	1	-	1	-	-
	500 to 999	60 to 75%	-	3	-	3	-	1	-	-
	more 1000	more 75%	12	2	8	3	3	-	2	1
more 1000	less 50	less 15%	-	-	-	-	-	-	-	-
	50 to 99	15 to 30%	-	-	-	1	-	-	-	1
	100 to 299	30 to 45%	-	-	-	1	-	-	-	-
	300 to 499	45 to 60%	-	-	-	-	-	-	-	-
	500 to 999	60 to 75%	-	-	-	4	-	-	-	1
	more 1000	more 75%	-	-	9	3	-	-	5	2
			62	41	74	59	71	58	77	62

- Most companies (80%) work for the internal market. Main exporter companies are large. However, it is possible to identify exporters in all levels.

Cotton sub-sector:

- A significant number of companies (40%) export their products. In general, these companies have more than 200 employees. Except for some exceptions, small size companies produced mainly for the internal market.
- All the companies with more than 100 employees had a turnover greater than 500 MPtes.

Knitting sub-sector:

- All the companies that sell over 1000 MPtes had more than 200 employees.
- Most companies (from different size categories) export their products. More than 40% of the inquired companies export more than 75% of their production.
- Small size companies (less than 50 employees) tend to work for the internal market. Companies with more than 200 workers tend to work for exportation.

Clothing sub-sector:

- Companies that sell more than 1000 MPtes had more than 200 employees. All companies with more than 500 employees had a turnover greater than 1000 MPtes, and their production goes mainly to external markets.
- Most companies (more than 80%) export their products. The greater the company, the greater the probability to export to external markets. However, the existence of small size companies that work exclusively for foreign customers was found.

This "external" characterisation of the sample of inquired companies was followed by an "internal" characterisation of the companies' environment.

5.1.3. Social and human issues

5.1.3.1. Basic education

Quality performance can arise from a good business system/human interface. The human factor is critical and deep rooted. To examine this, educational and social issues were analysed. In terms of managers' basic education it was found that 45% of quality managers had a university or polytech degree (Figure 27). In no function is there more than 40% of managers with a university degree. This situation is certainly a constraint to the implementation and development of advanced quality systems in the companies. However, different sub-sectors presented different scenarios:

- *Wool sub-sector*: 65% of production and technical managers had a university or politech degree; 46% of quality managers had a university or politech degree; there were a lot of managers with an education level lower than high school, mainly at the supervisors level (around 30%).
- *Cotton sub-sector*: 63% of production and technical managers had a university or politech degree; 50% of quality managers had a university or politech degree.

- *Knitting sub-sector*: 40% of production and technical managers had a university or politech degree; 32% of quality managers had a university or politech degree; there was a predominance of managers with high school education (45%).
- *Clothing sub-sector*: 48% of production and technical managers had a university or politech degree; only 25% of quality managers had a university or politech degree; there were a lot of managers with an education level lower than high school (around 10% in each functional area).

The situation found, mainly in the knitting and clothing sub-sectors, can be a constrain to the implementation and development of quality systems, and to the creation of a lean environment.

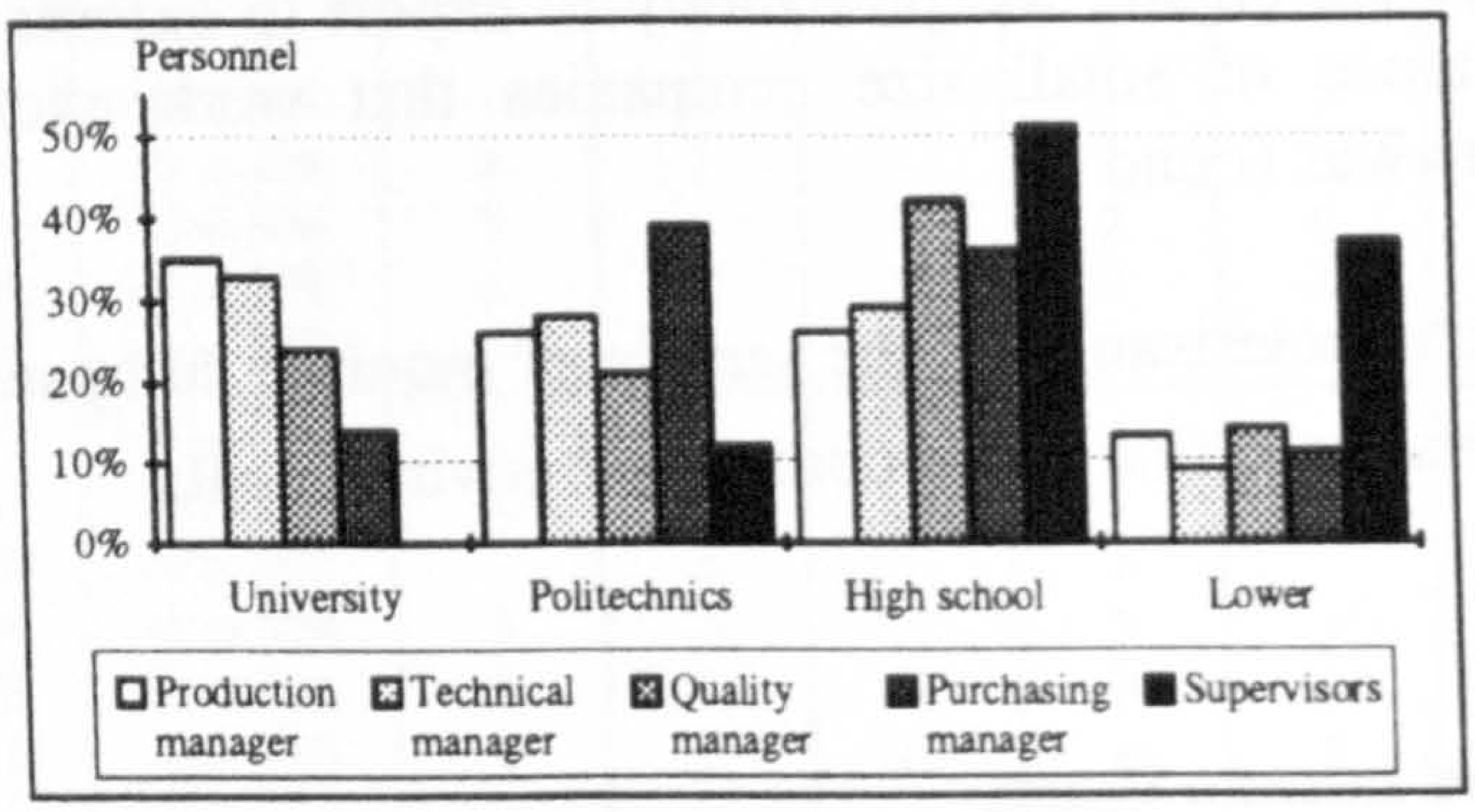

Figure 27 - Basic education

5.1.3.2. Social environment

In the characterisation of social and labour aspects it was found that the survey companies do not have major problems. The working environment was considered "excellent" or "good" for almost all companies (91%). Figure 28, shows the situation of social and labour relationships in the companies of the different sub-sectors. The existence of a good social environment is vital for the implementation of quality systems. The situation was found to be favourable to the introduction of quality principles.

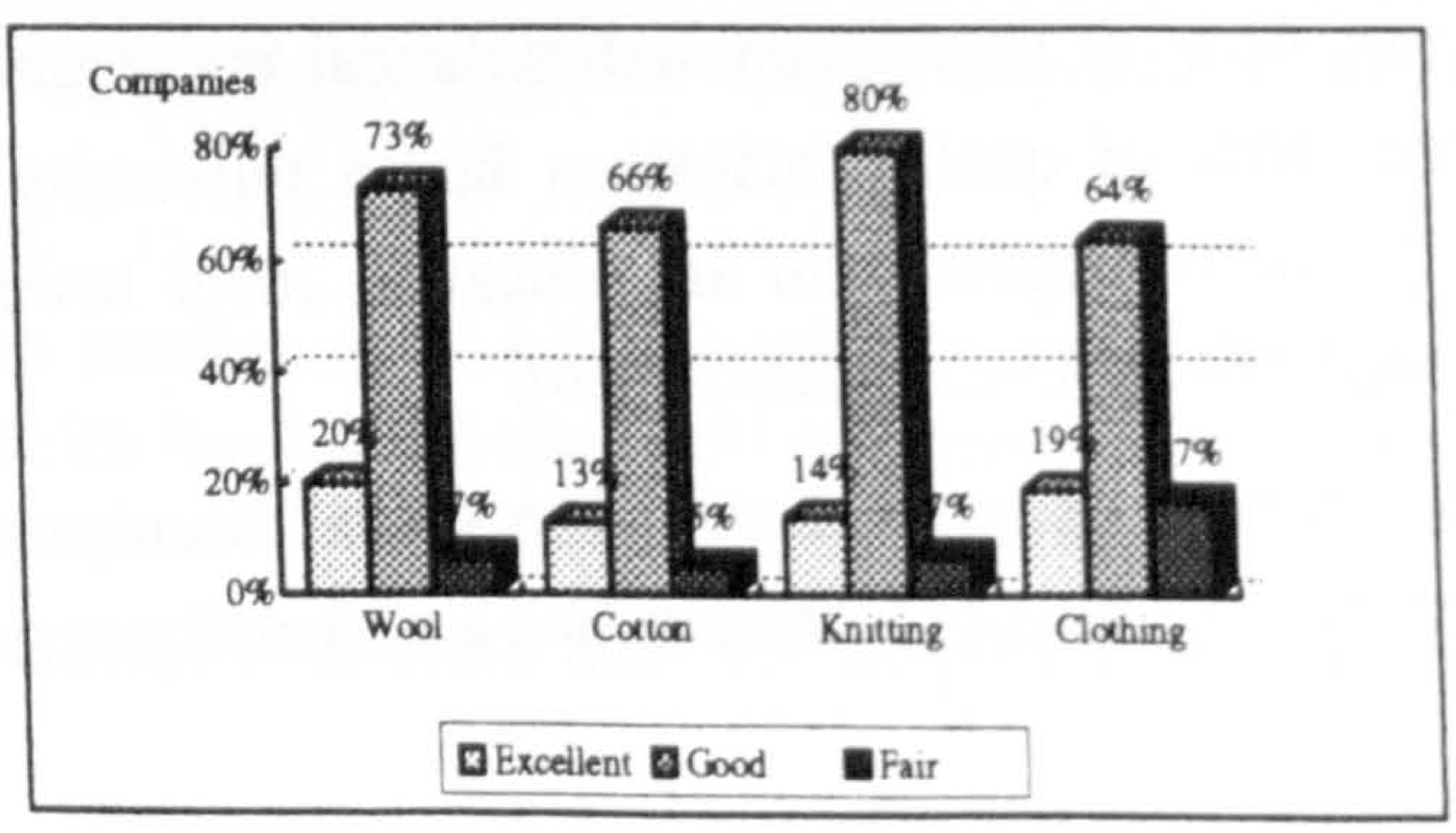

Figure 28 - Social and human relationships

5.1.4. Technology and support

The questionnaire was designed to include issues related with the use of technology and its relevant support functions. Table 17 and Figure 29 show which technologies were being used in the companies surveyed. This table reveals some deficiencies concerned with the computerisation of key functions of the organisation. The use of office automation systems is well advanced in all the sub-sectors, but the computerisation of production planning and control systems and CNC technology is missing in many companies (nearly 50% from all sub-sectors). In particular the use of CAD/CAM systems was low but growing at a high speed. In knitting and clothing, 40% of the companies use CAD/CAM systems. In wool (10%) and cotton (22%) sub-sectors the situation is not so advanced, but it was visible from companies' comments that there was an intention to invest in CAD/CAM systems. This situation was more critical for those companies with a smaller size. Most larger companies (more than 500 employees) used all the above technologies.

Table 17 - Technology support

No. of employees	Office automation systems				Production planning & control computerisation				CNC machines				CAD/CAM			
	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl
<50	9	15	14	10	9	6	2	3	3	7	6	8	-	2	2	3
50 to 99	14	8	21	12	6	3	13	7	7	5	10	5	-	2	8	2
100 to 199	13	12	10	18	6	7	5	7	4	4	6	5	2	3	3	3
200 to 499	11	21	16	16	6	9	8	8	9	8	8	5	2	2	13	12
500 to 999	13	7	3	3	9	3	2	2	9	3	3	2	3	2	3	2
>1000	-	8	-	5	-	9	-	5	-	8	-	5	-	7	-	3
W - Wool; Co - Cotton; K - Knitting; Cl - Clothing																

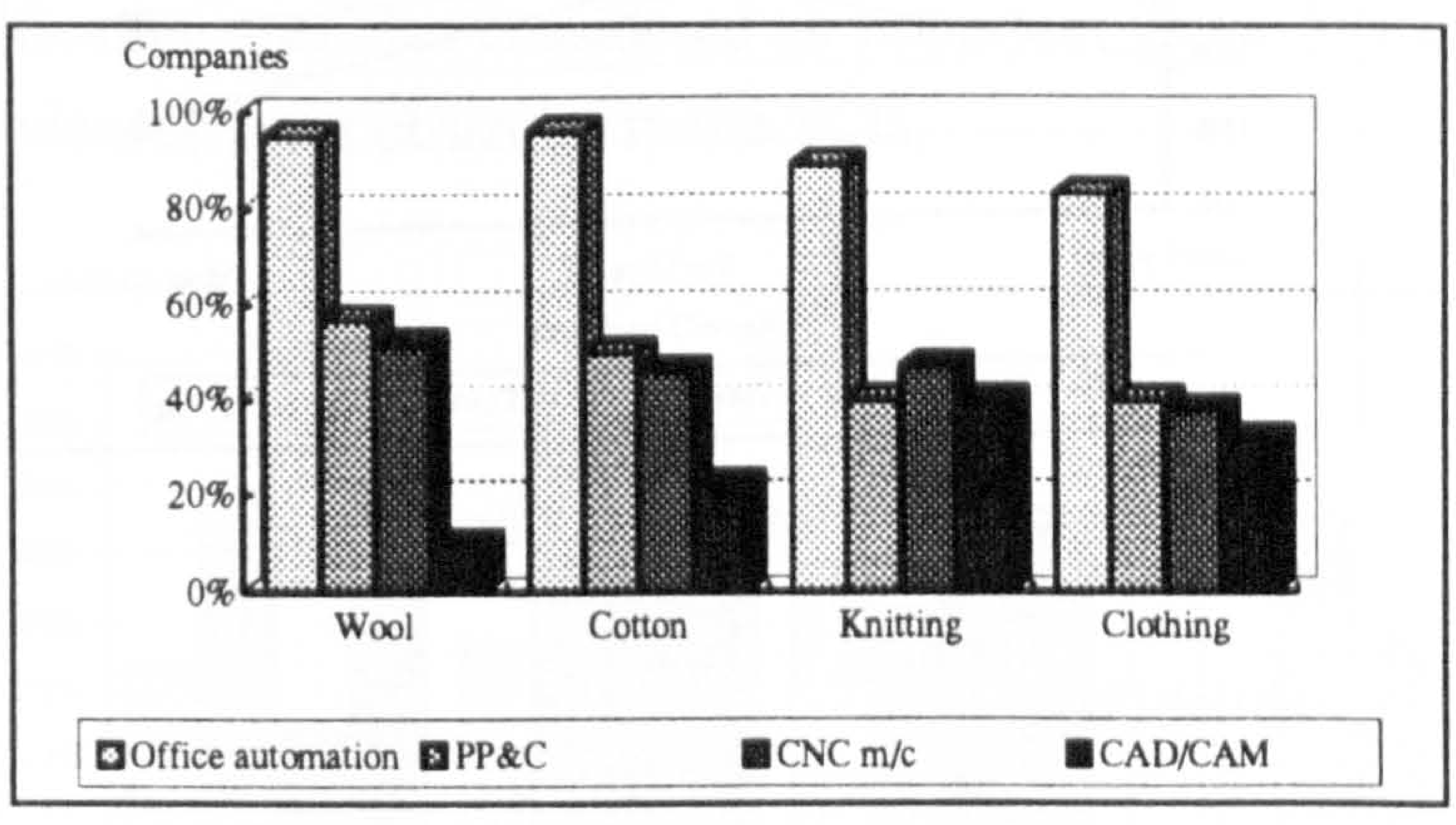

Figure 29 - Computerised facilities supporting the industrial activity

5.1.4.1. Equipment obsolescence

Figure 30 shows the average age of the equipment (main machines) in the different sub-sectors:

- *Wool sub-sector*: most companies had quite old equipment - 80% of the companies had their main equipment with more than five years old, and near 50% of the companies had equipment more than 10 years old.
- *Cotton sub-sector*: the inquired companies of this sub-sector revealed to be younger than the wool sub-sector - 40% of the companies had equipment with less than 5 years old, but quite 30% of the companies had very old equipment (more than 10 years old).
- *Knitting sub-sector*: these companies revealed a quite updated technology - more than 55% of the companies had equipment with less than 5 years and only 13% had equipment with more than 10 years old. Technology is not a constraint to the development of this sub-sector (we will see later on that companies do not consider technology as a limiting success factor).
- *Clothing sub-sector*: most companies (75%) had equipment with less than 10 years old. Although there has been a high evolution in advanced manufacturing technology in recent years, it is considered that technology is not a constraint to the development of this sub-sector.

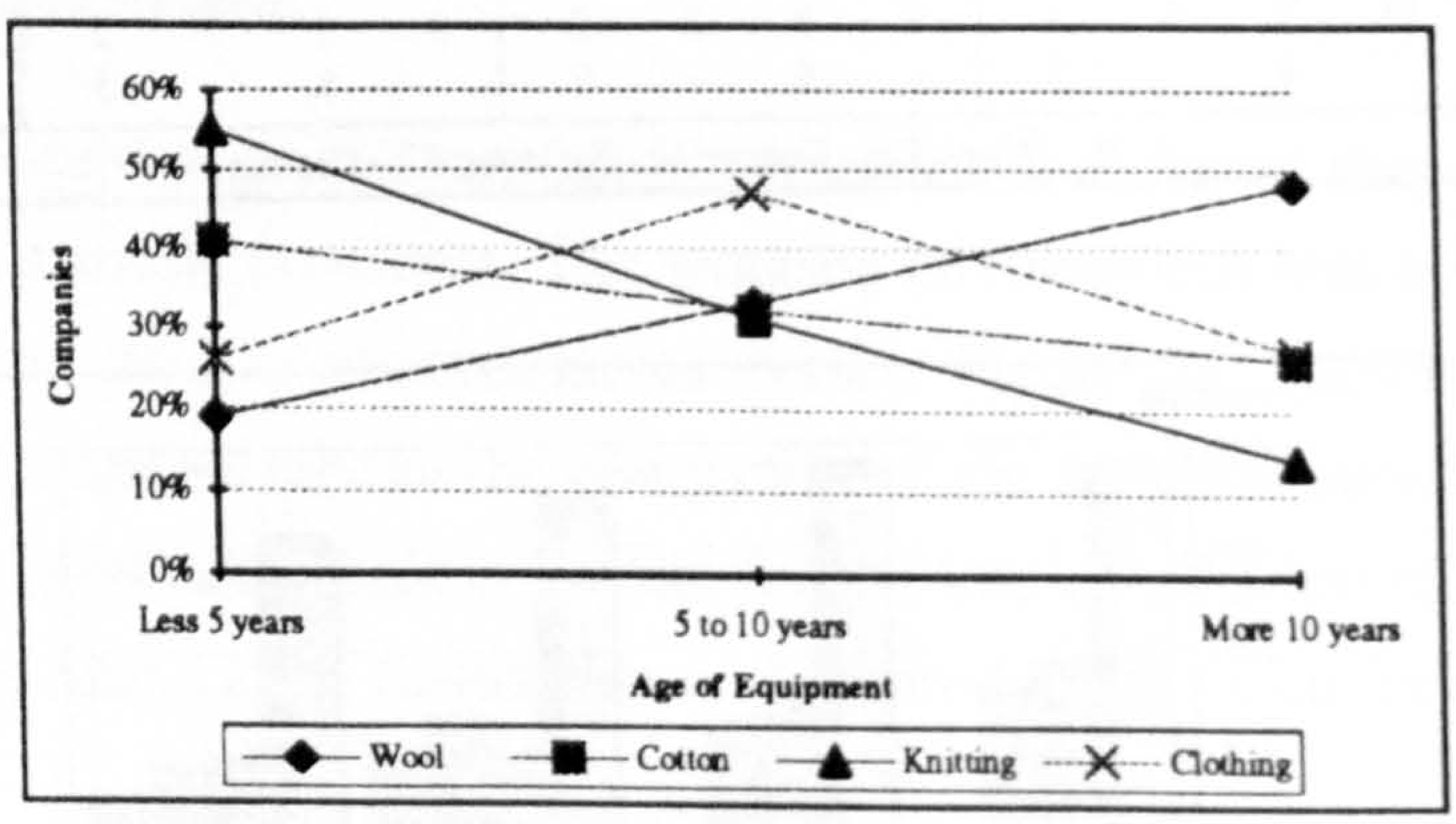

Figure 30 - Equipment obsolescence

5.1.4.2. Capacity availability

Most companies are working below their production capacity. Figure 31 shows this situation for the sub-sectors (in October 1992):

- *Wool sub-sector*: most companies (74%) referred to be working above 70% of their installed capacity.

- *Cotton sub-sector*: 56% of the companies referred to use more than 80% of their installed production capacity.
- *Knitting sub-sector*: 36% of companies were working at 70% of their installed production capacity, 24% of companies were working at full capacity.
- *Clothing sub-sector*: most companies (78%) were working above 70% of their installed production capacity, and near 20% of the companies answered that they were working at full capacity.

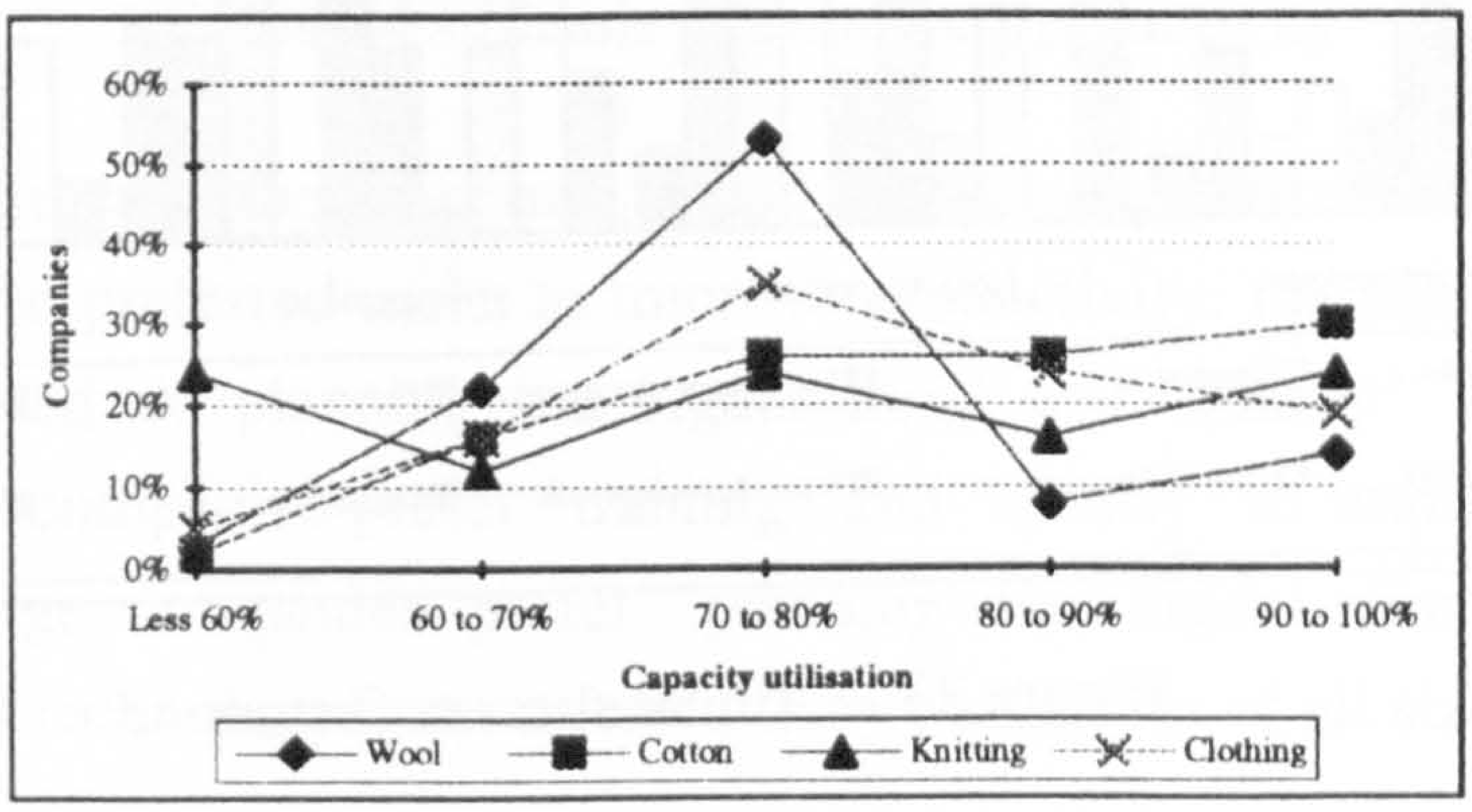

Figure 31 - Capacity utilisation

5.1.5. Main obstacles

"Financial factors" were generally considered as the main obstacles to the development of textile industry (65%). This situation is independent of the sub-sector nor the size of the companies. The "capacity to deliver on time" and "prices not competitive" are other important obstacles. In a different perspective, the level of personnel qualification was also considered an important factor of success. Figure 32 shows a global view of main obstacles in the TCIs.

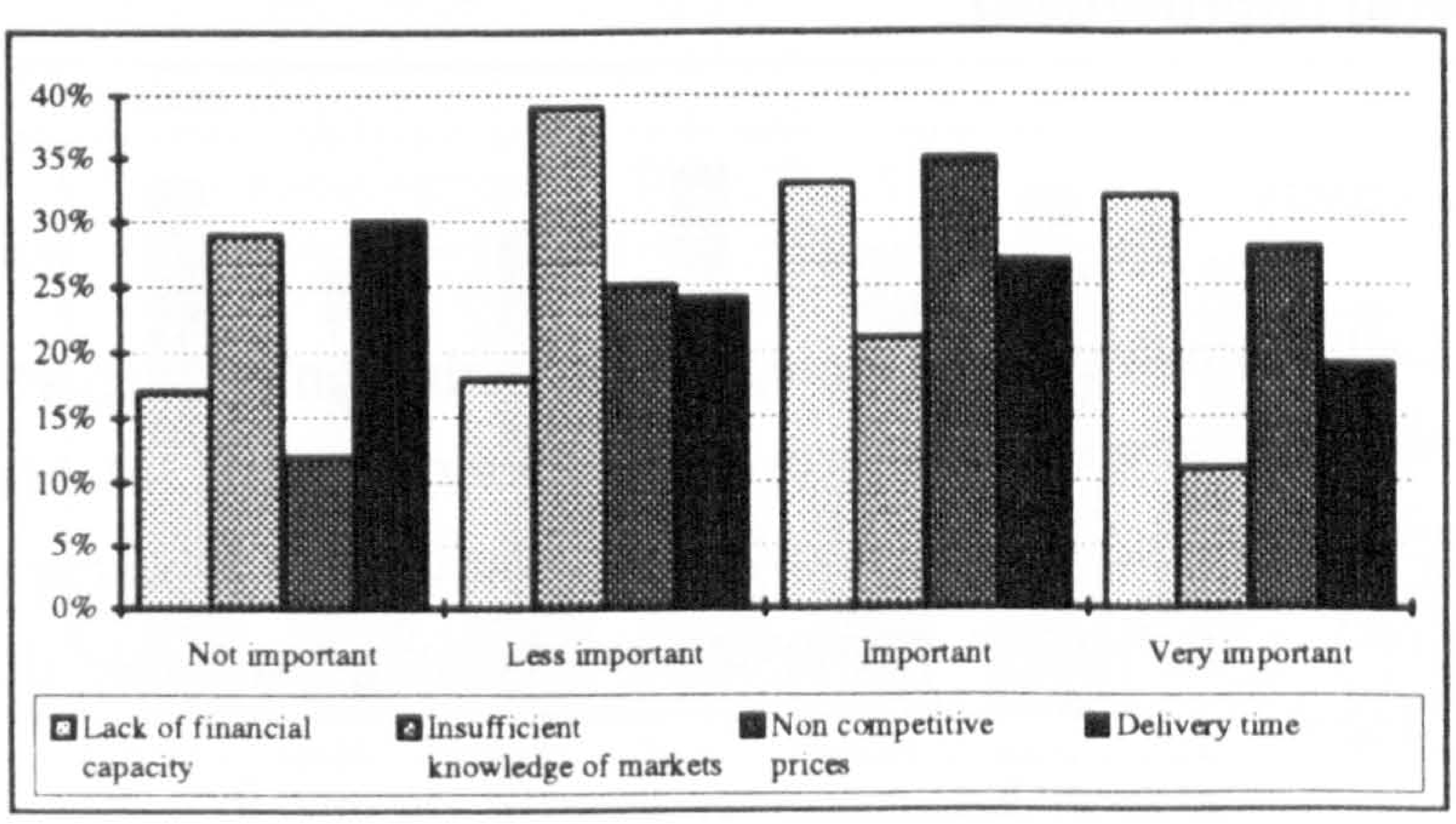

Figure 32 - Main obstacles in the TCIs

Figure 33 shows a set of factors that were considered important for the success of the companies. They complement the main obstacles that were found.

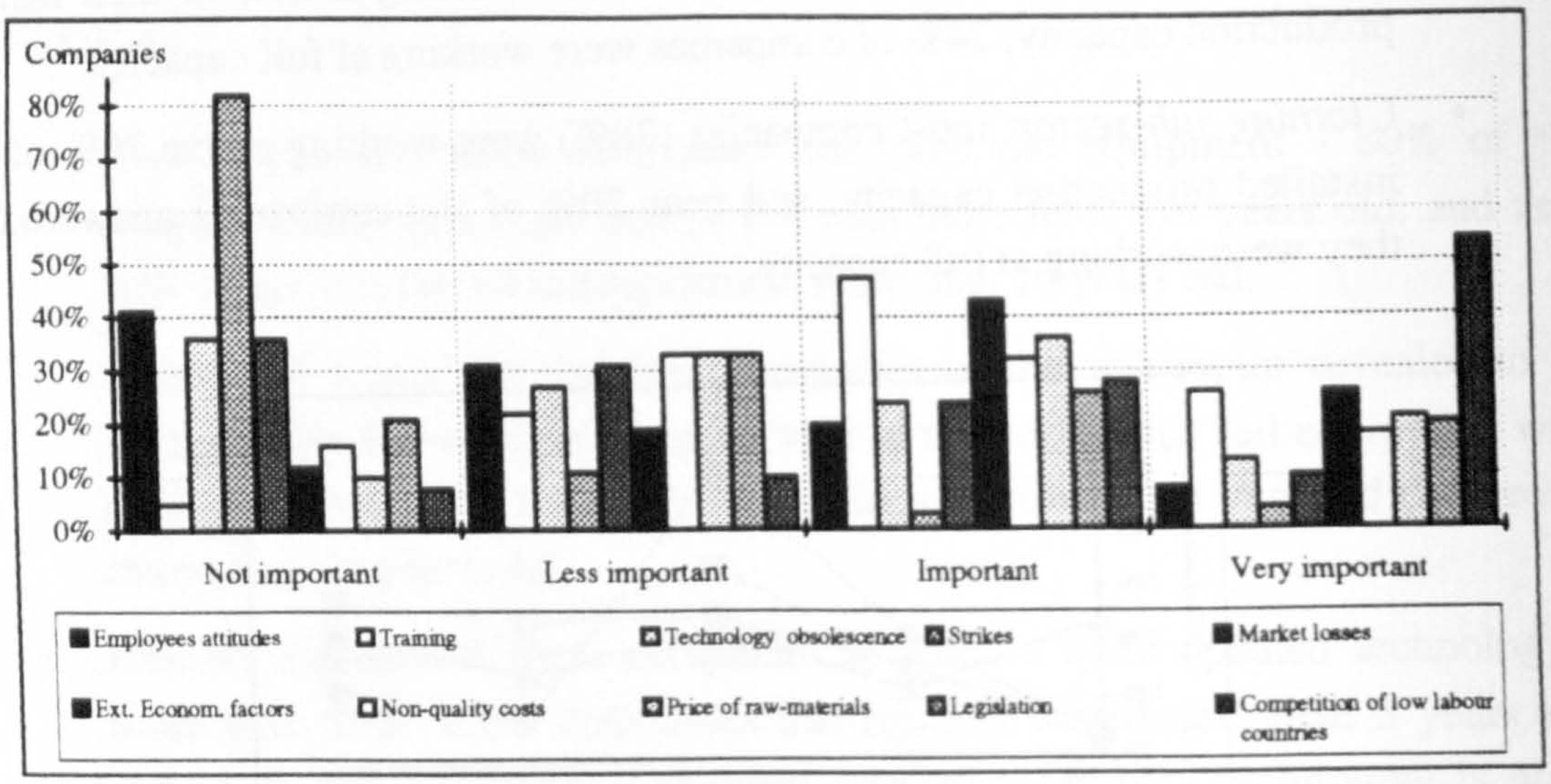

Figure 33 - Critical success factors

The "competition of low labour cost countries" is one of the main obstacles to success. It was considered very important and important by 54% and 29% companies, respectively. Curiously, it did not depend on the company size. "Training" and "external economical factors" were also considered as very important or important for companies of every size. In another level, "technology obsolescence", "non-quality costs" and "legislation" were considered also important concerns. Again, the technological factors show the need to update technology in this industry. Curiously, "employees attitudes", "market losses" and, specially, "strikes" were considered as less or not important.

5.1.6. Means of improvement

5.1.6.1. Productivity

"Automation and technology", "planning and organisation", "quality", and "training" were considered the best ways to improve productivity (Figure 34). More than 80% of companies considered these factors as very important or important. "Laws" were referred to as not important in improving productivity by more than 20% of the inquired companies.

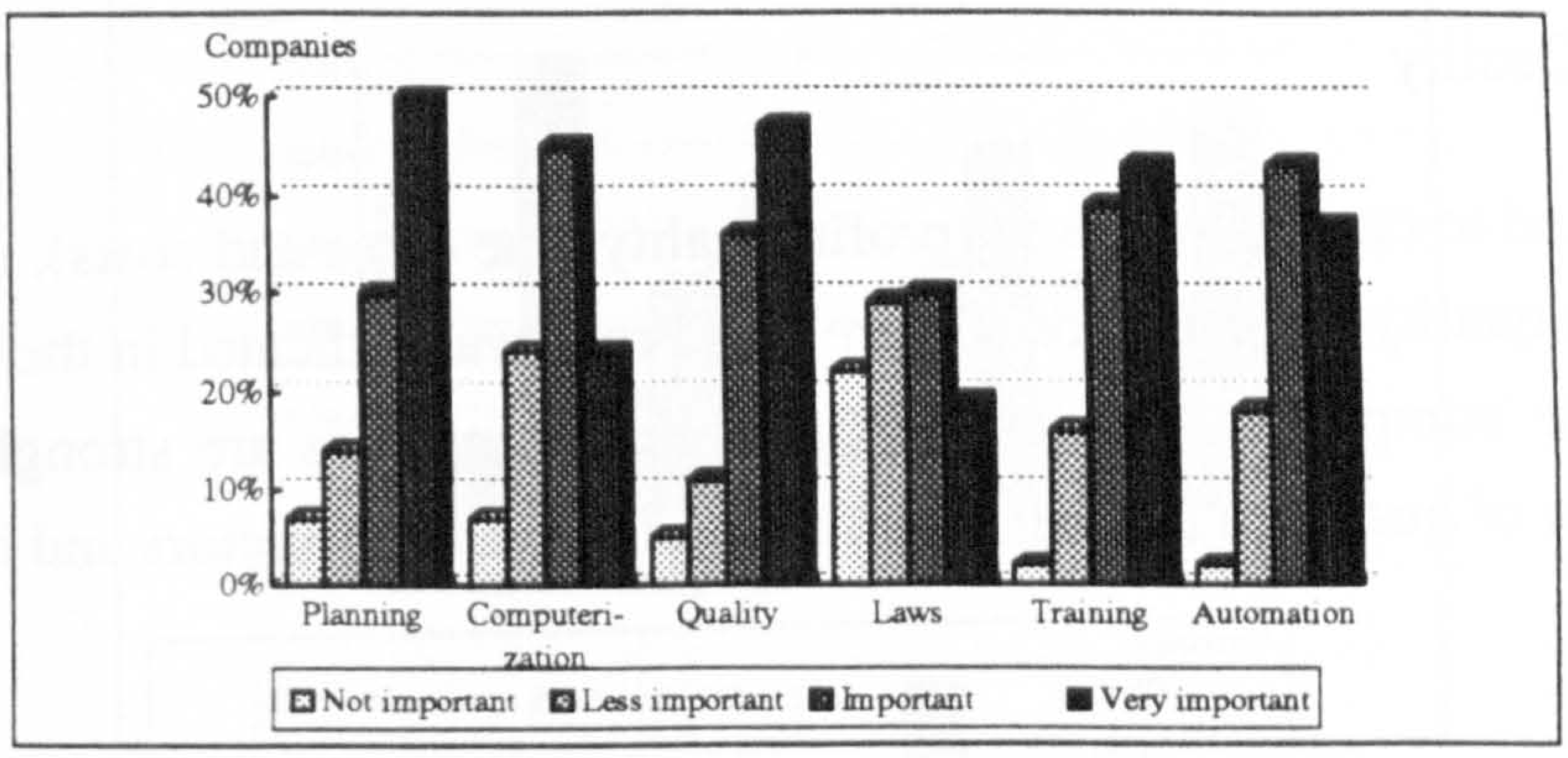

Figure 34 - Means to improve productivity

In terms of sub-sectors: the wool and cotton companies referred to "automation and technology" as the preferred mean to improve productivity; the knitting and clothing sub-sectors referred to "planning and organisation" and "quality". In terms of company size: small companies prefer "training" and "quality" to improve productivity; medium and large companies prefer "planning and organisation" and "quality". "Automation and technology" was referred to by companies of all sizes.

5.1.6.2. Cost

The "technology factors" (85%) and "quality improvements" (80%) were considered adequate means to reduce costs. Factors like "manufacturing processes", "training" and "motivation" improvements were also considered important factors for cost reduction (Figure 35). Curiously, the factor "suppliers" was referred to by more than 50% of the companies as being less or not important. In the clothing sub-sector a special emphasis was given to the control of "manufacturing processes" to reduce costs. In terms of company size: small companies preferred technological improvements to reduce costs; medium companies preferred "quality" and "training" improvements; large companies preferred "quality" and "motivation" improvements.

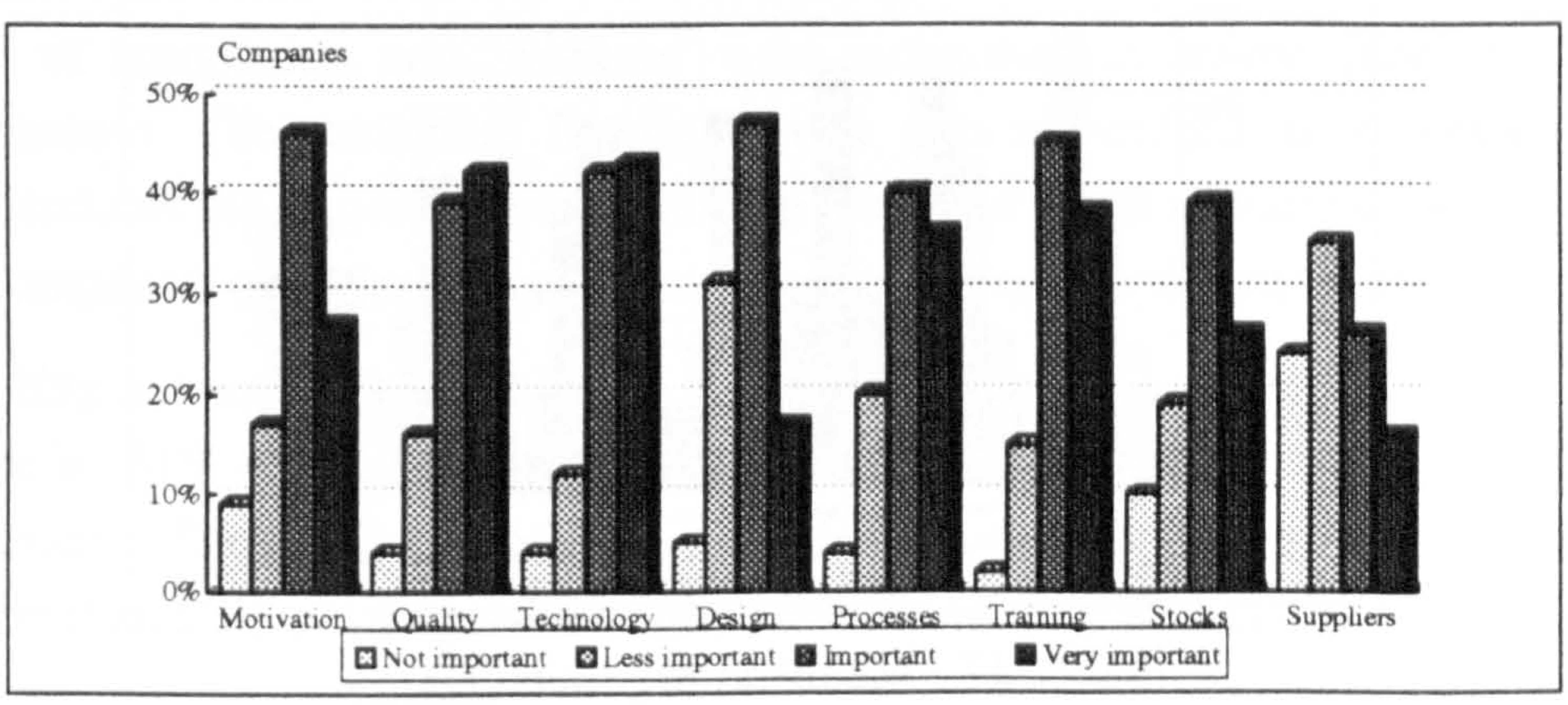

Figure 35 - Means to reduce costs

5.1.6.3. Quality

When asked to rank four factors (profit, quality, due dates and costs), most companies (75%) put quality in first place (Figure 36). Profit was indicated in the last position by 45% of the companies. This fact suggests that companies are strongly aware of the importance of quality. This scenario was similar in all sub-sectors and company sizes.

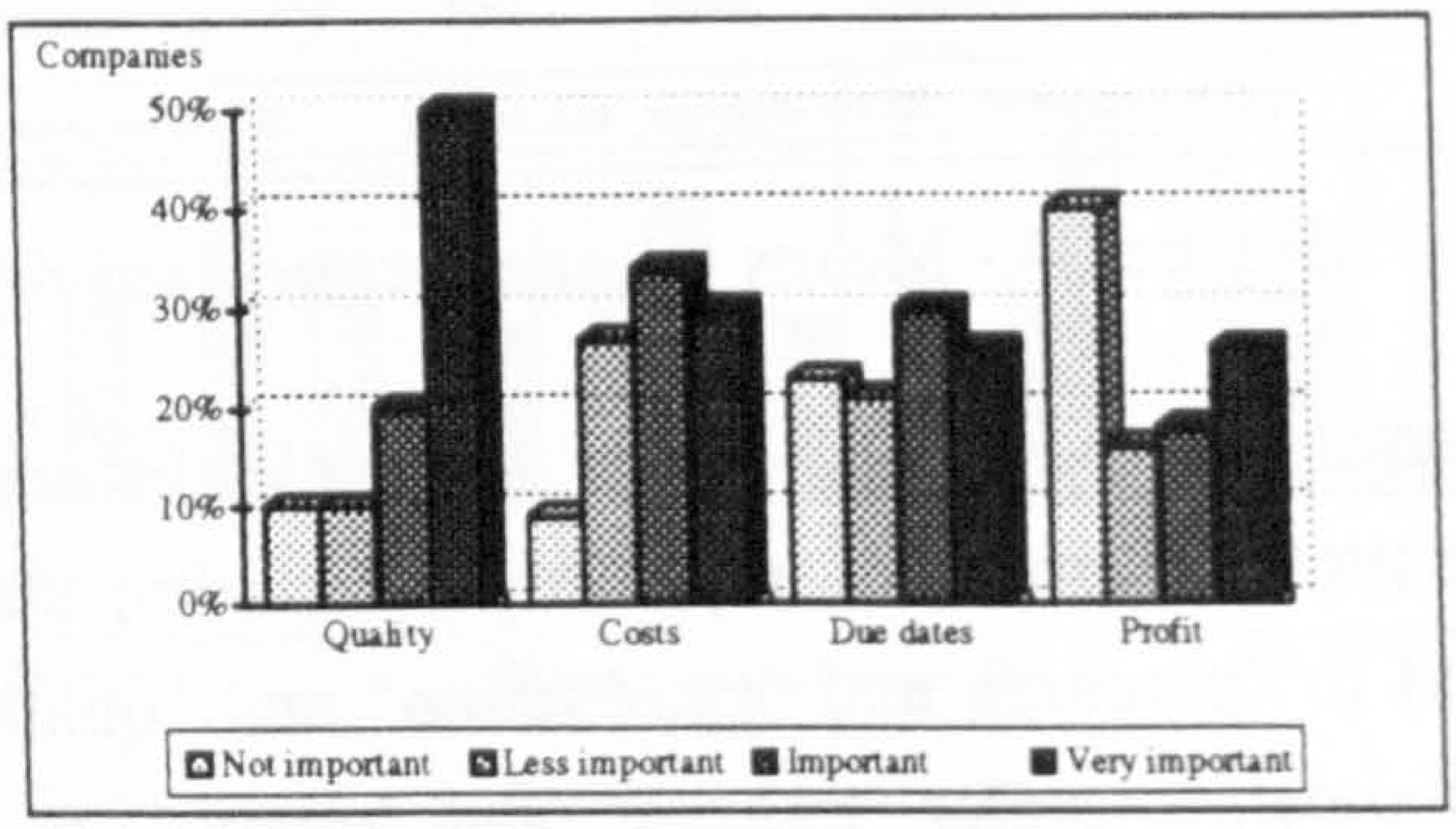

Figure 36 - Ranking by importance

The companies were also asked which were the best means to improve quality. "Training of employees" (78%), "manufacturing process control" (76%), and "equipment improvements" (67%) were considered good means for quality improvement (Figure 37). This scenario was similar to all sub-sectors. However, some differences were found in what concerns to "suppliers control" and "customer service" factors. Wool and cotton companies did not seem to give much attention to suppliers selection and control, and customers service. More than 50% of wool companies and 40% of cotton companies considered these factors as less or not important. On the opposite side, knitting and, specially, clothing companies gave much more importance to suppliers control and customer service. This situation allows identification of two groups of companies with different relationships between them and their suppliers and customers. The described situation is more evident for medium and large companies.

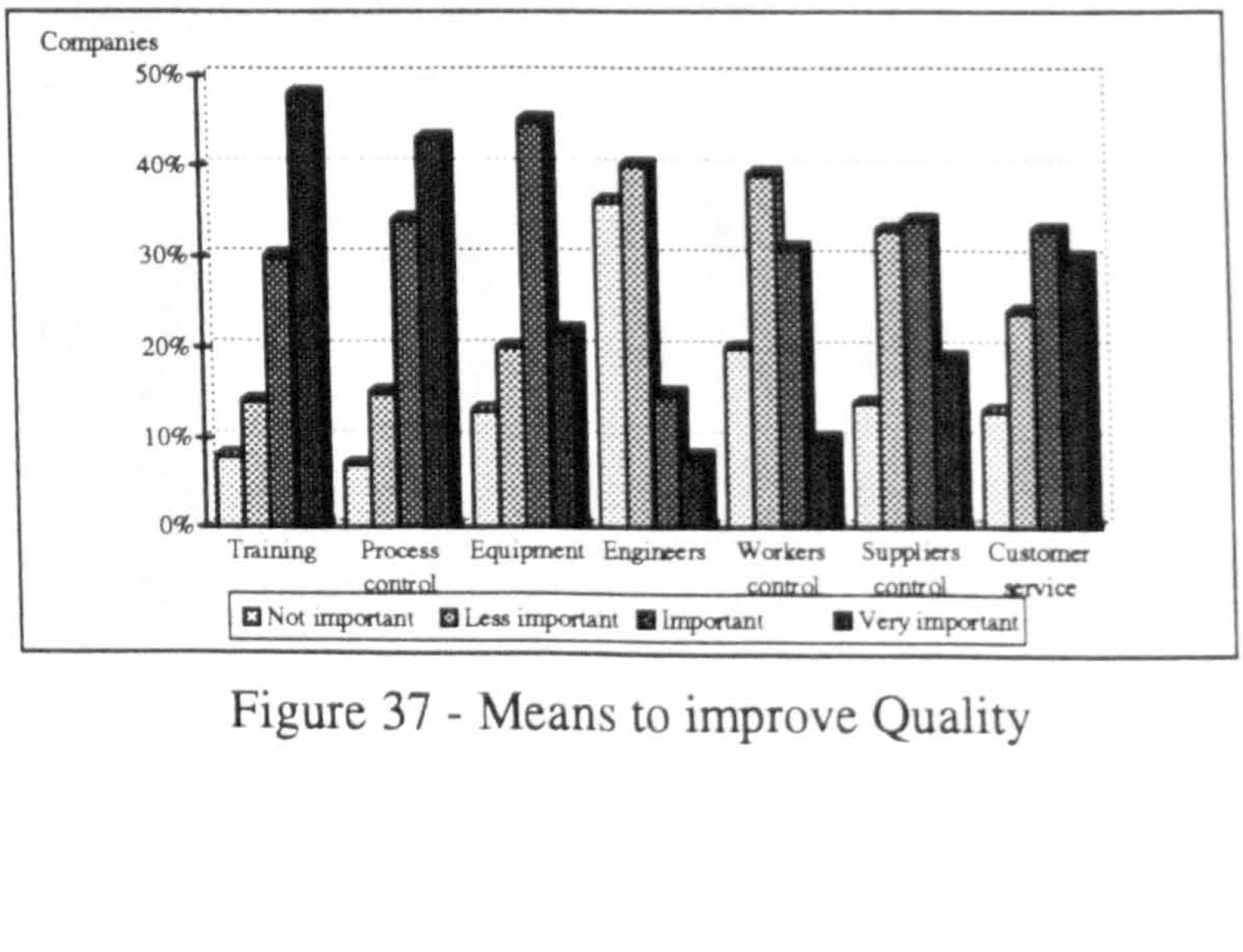

Figure 37 - Means to improve Quality

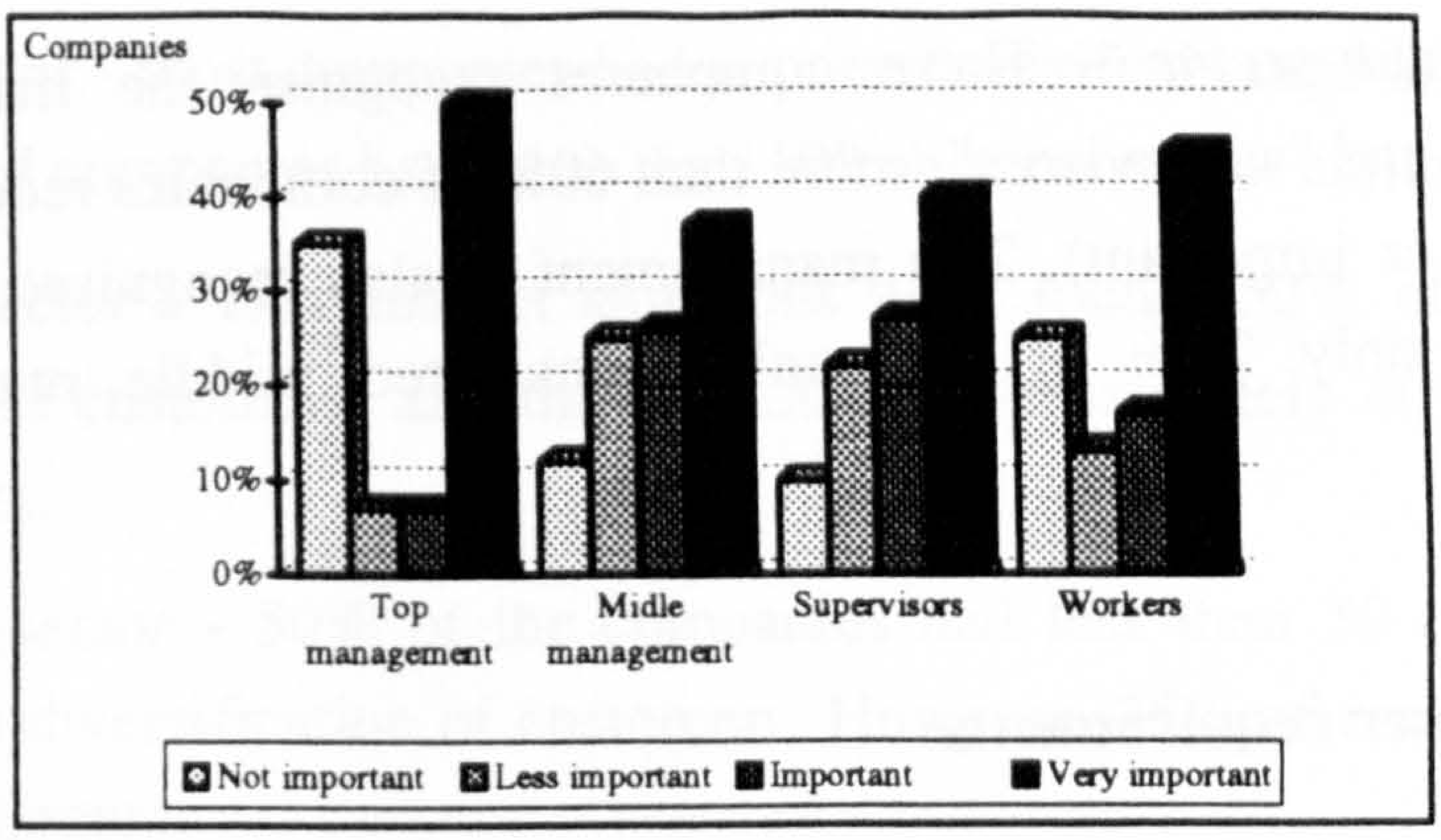

Figure 38 - Importance of people for quality

The role of all human resources were recognised as very important for the development of the quality function. The importance of top management is recognised by 60% of the companies. It is evident the importance of this situation on the implementation of quality systems (Figure 38). However, 40% of the companies still think that the role of top management is less or not important. This situation can be illustrated if we look at the different sub-sectors:

- *Wool sub-sector* - Most companies recognise the importance of human resources in the quality area. However a significant number of companies answered that "top managers" (45%) and "workers" (25%) were not important in the quality domain. This scenario suggests that companies consider the role of middle managers and supervisors as determinant for quality improvement: more than 70% of companies recognised them as very important or important. These facts must be considered with some concern because: 1. it is well recognised that the involvement and commitment of top management is vital for a successful implementation and development of a quality system; 2. in addition, its speed and effectiveness of implementation depends heavily on real involvement and participation of all resources, namely, from workers.

- *Cotton sub-sector* - The role of "top management" in quality was recognised by 50% of companies, and "workers" were recognised in second place by 41% of companies. The remaining functions were also recognised as important, which evidentiates the importance that is being attributed to all resources. However, 28% of companies considered that top management is not important for the quality.

- *Knitting sub-sector* - The role of top managers appears to be recognised in first place by 51% of companies. This function was immediately followed by the other functions. These companies privilege also the function of middle management (more than 60% of companies referred to them as very important or important).

- *Clothing sub-sector* - These companies recognise the major importance of "workers" and "supervisors" (more than 60% of companies recognise them as very important or important). Top management is also recognised as very important. However, only 20% of companies considered middle management as very important.

5.1.7. Customer requirements

In general, "delivery on time" (93%) and "quality assurance" (76%) were referred to as vital requirements from customers (Figure 39). The scenario is similar to all sub-sectors. It is interesting to notice that "test equipment" is becoming an important requirement for knitting companies. This is probably due to some lack of laboratories in this sub-sector. Older sub-sectors like wool and cotton tend to have more laboratorial facilities; for all large companies this is an important requirement.

Another comment must be addressed to the "quality assurance" requirement. Quality assurance was frequently misunderstood as product quality. The prevention character of quality assurance presupposes the use of quality assurance standards and these were not referred to often. Many companies indicated only product standards.

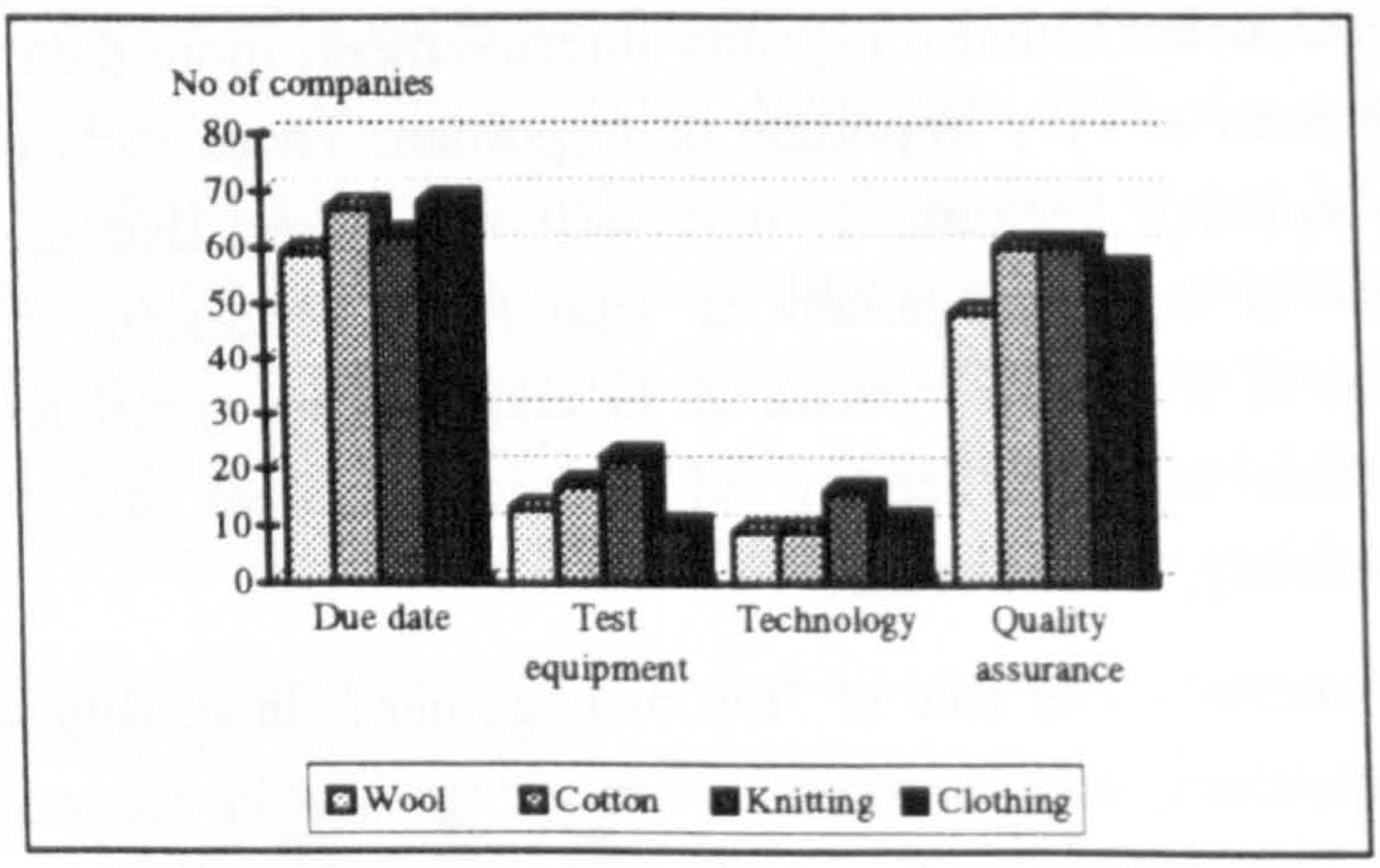

Figure 39 - Main customer requirements

5.1.7.1. Customers

Figure 40 shows the customers distribution by sub-sector. Some main differences were found, namely:

- *Wool sub-sector* - most companies had a quite diversified range of customers. 70% of the inquired companies had more than 100 customers (per company).
- *Cotton sub-sector* - two distinct situations were found: 52% of companies had more than 200 customers, and the remaining, approximately 40%, had less than 100 customers.
- *Knitting sub-sector* - 50% of the companies had less than 50 customers, which reveals a less diversification of customers. However, 25% of companies had more than 200 customers.
- *Clothing sub-sector* - The range of customers for these companies is not diversified - 63% of companies work for less than 50 customers. However, there is a group of (medium and large) companies (34%) that produced for more than 200 customers.

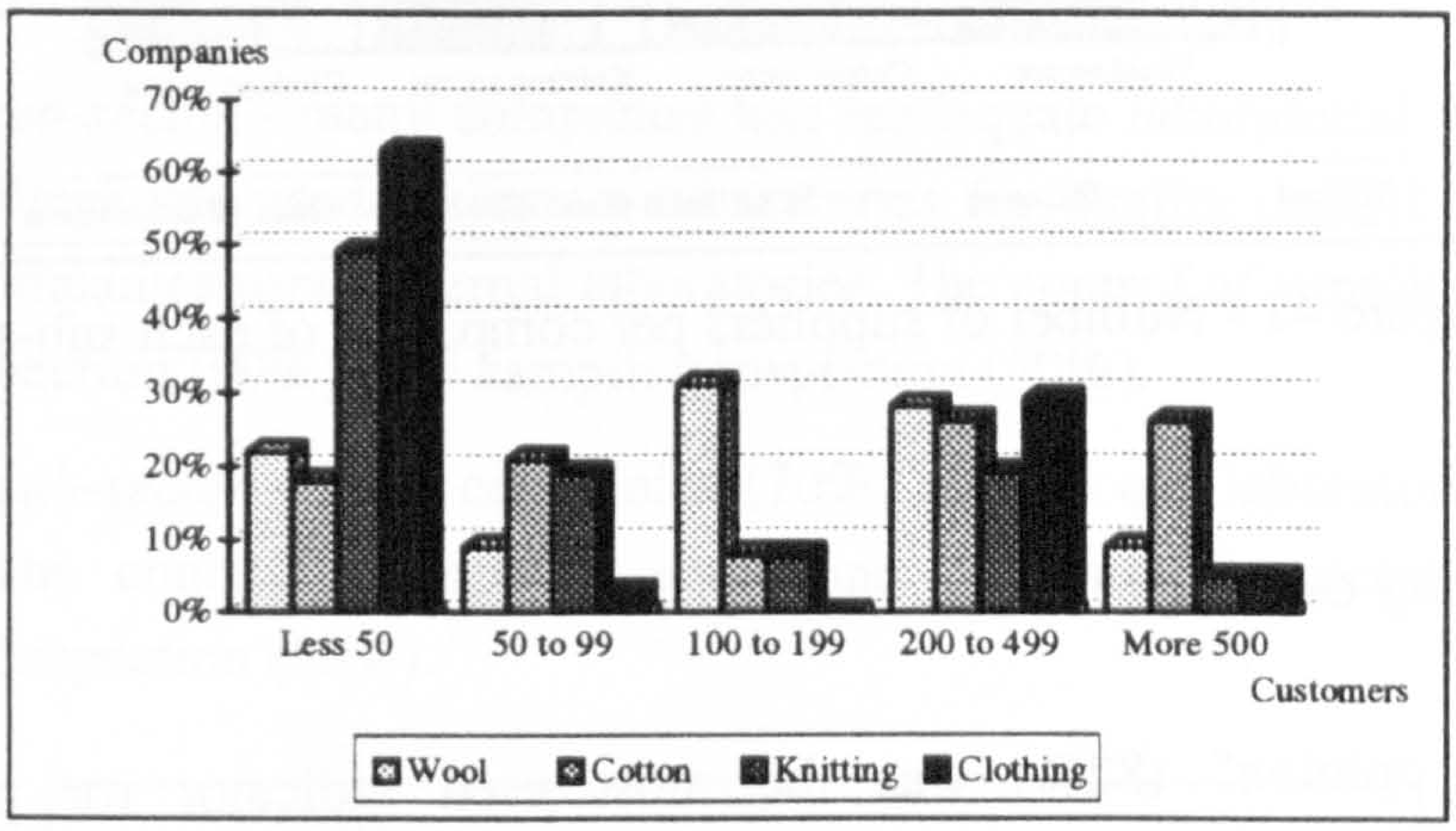

Figure 40 - Number of customers per company of each sub-sector

5.1.7.2. Suppliers

The supply chain was also quite different for the sub-sectors (Figure 41). Some observations are:

- *Wool sub-sector* - most companies buy main raw material in the national market. Artificial and other fibres depend mainly on international suppliers. In this sub-sector each company has an average of 15 main suppliers.
- *Cotton sub-sector* - most raw materials are ordered from international suppliers. Only synthetic fibres are bought in the national market. In this sub-sector each company has an average of 10 main suppliers.
- *Knitting sub-sector* - in general, companies are supplied by national suppliers. In this sub-sector each company has an average of 15 main suppliers.

• *Clothing sub-sector* - in general, companies are supplied by national suppliers. In this sub-sector each company has an average of 18 main suppliers.

In this sample of companies, it appears that the number of suppliers per company is small enough to allow good relationships. In fact, it is evident if we look at section 5.1.12: suppliers were considered the best external institution to help solving problems with quality.

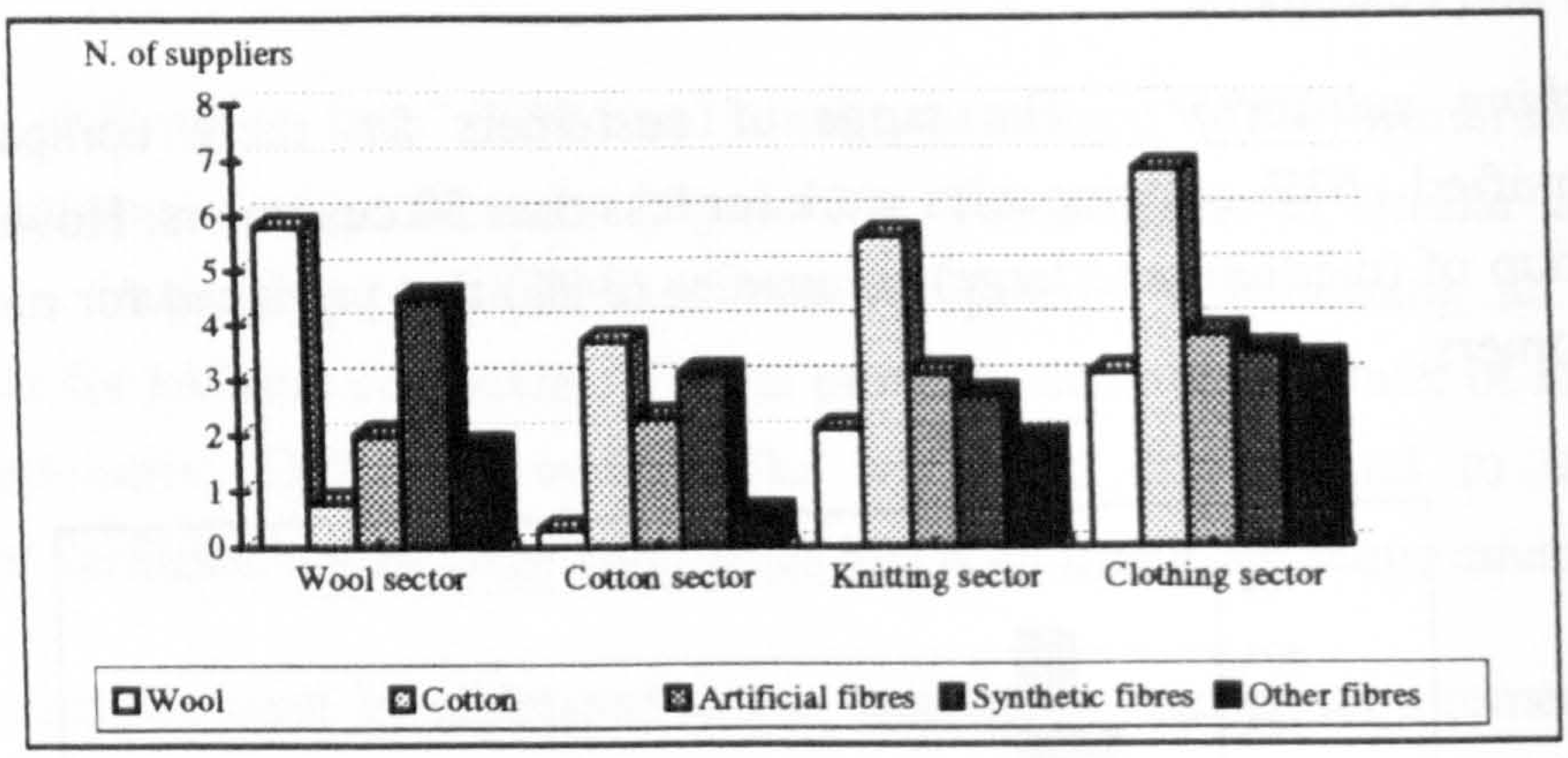

Figure 41 - Number of suppliers per companies of each sub-sector

5.1.8. Quality control

"Customers opinion" (82%) was the most used indicator for product quality performance (Figure 42). "Quality control reports", "comparison with competitors" and "customer complaints" were also considered important indicators for the quality assessment. This scenario was similar to all sub-sectors and companies size. It is interesting to point out that only 22% of the companies referred to the use of quality costs for this purpose. However, company audits subsequently revealed that some companies were not using this tool effectively.

A significant part of companies used laboratories for quality control of supplies and work-in-process. The scenario for each sub-sector is quite different:

• *Wool sub-sector* - a significant part of companies (50%) used their own laboratories for control of supplies and the usual quality control tasks (Figure 43). For specific tests they used external laboratories. Most companies used visual inspection (79%), and sampling inspection (80%). However, only 29% used statistical methods (see Figure 47). This suggests a deficient use of sampling techniques. This situation was validated on the audits.

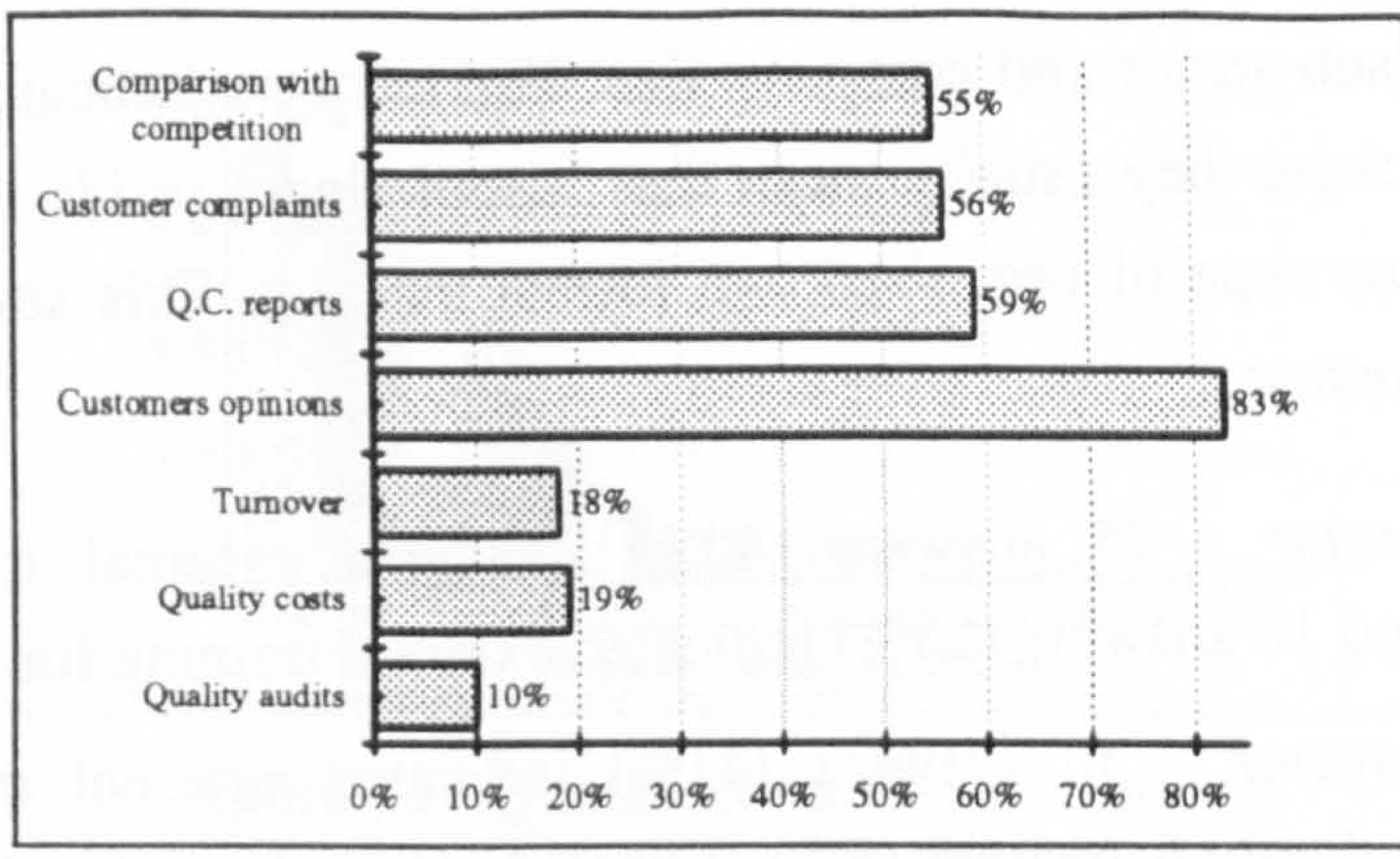

Figure 42 - Main indicators of product quality

- *Cotton sub-sector* - most companies (70%) had laboratories, and only some companies (26%) used external laboratories. Most companies used visual inspection (59%), and sampling inspection (59%). The previous comment on the use of statistical methods can also be applied to these companies.
- *Knitting sub-sector* - many companies had inadequate laboratorial facilities. Only 29% of companies used their own laboratories for quality control purposes, and 36% of companies used external laboratories. The control of supplies was done by visual inspection (90%), and sampling inspection (50%).
- *Clothing sub-sector* - most companies (70%) did not use laboratories for quality control. The control of supplies was done by visual inspection (85%), and sampling inspection (50%).

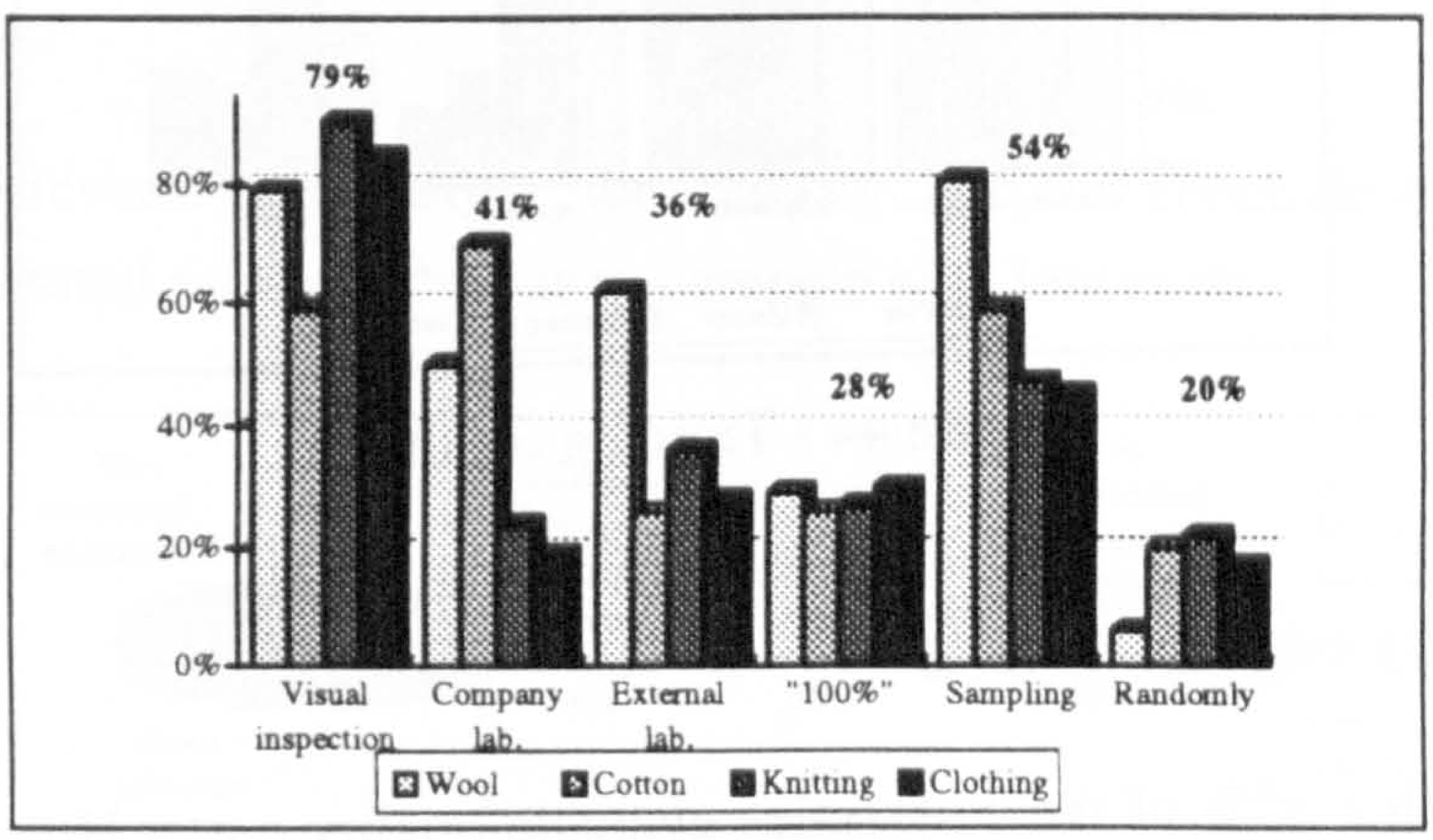

Figure 43 - Control of inward goods

5.1.9. Training

In terms of qualified personnel it was found that only a few people attended specific training courses for quality control. This is a critical constraint for the application of quality methodologies and practices. Figure 44 show the scenario of specific training for quality, by sub-sector and company size. The answers indicating internal training are suspect, because they usually mean that "people learn inside the company on the job", and not any type of organised and formal training. This situation suggests the following comments:

- *Wool sub-sector* - 25 answers (40%) indicated external training for quality managers, and 14 answers (23%) indicated external training for inspectors.
- *Cotton sub-sector* - 30 answers (41%) indicated external training for quality managers, and only 6 answers (8%) indicated external training for inspectors.
- *Knitting sub-sector* - Only 8 answers (25%) indicated external training for quality managers, and 13 answers (18%) indicated external training for inspectors.
- *Clothing sub-sector* - Only 17 answers (22%) indicated external training for quality managers, and 4 answers (8%) indicated external training for inspectors.

It is clear that wool and cotton sub-sectors paid more attention to specific training for quality. However, it is evident that knitting companies are giving more external training to inspectors.

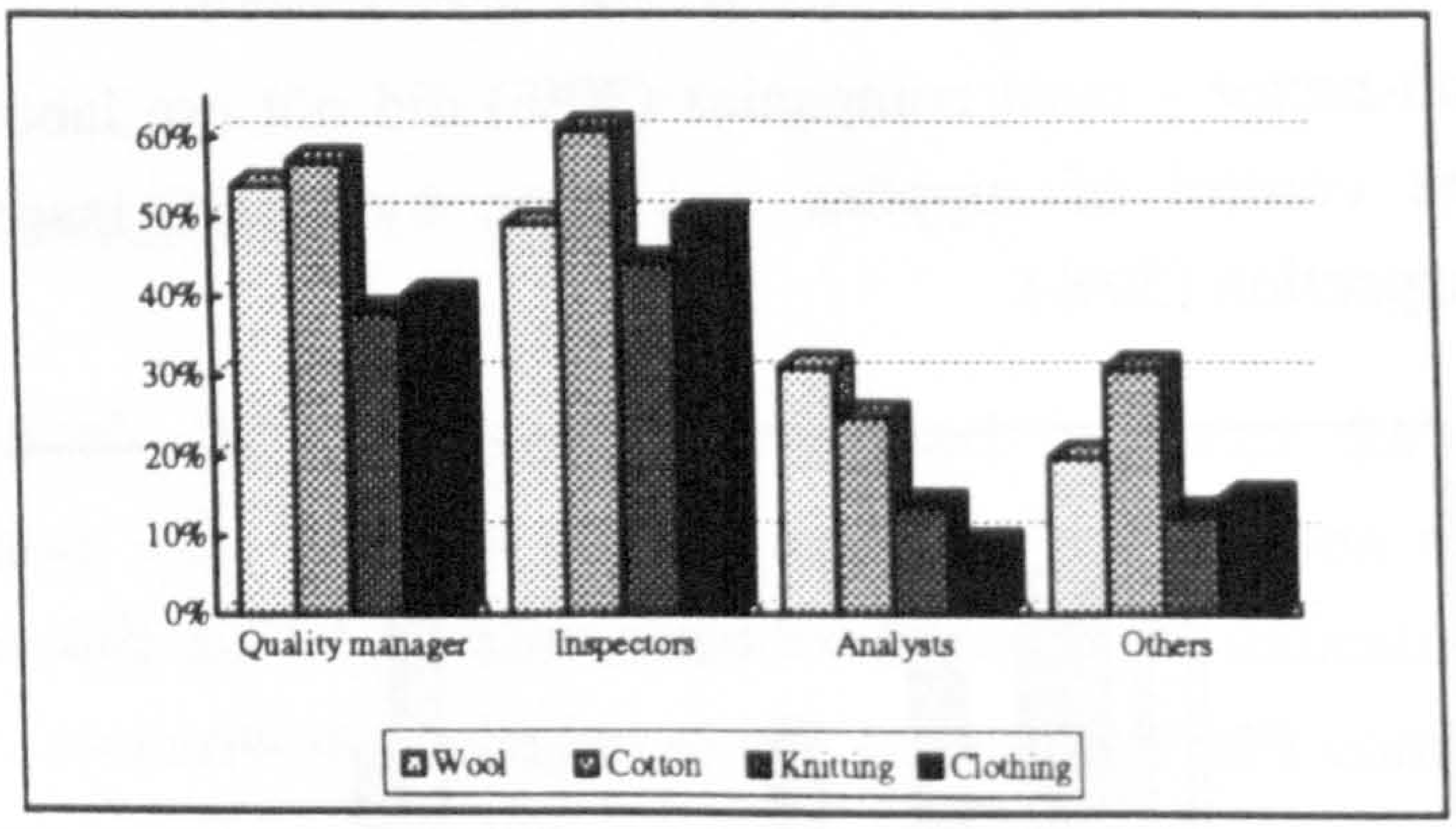

Figure 44 - Training for quality

5.1.10. Quality costs

It was found that 35% of the companies evaluate quality costs. However, the figures presented were not credible. The validation of these figures was done during the quality audits. It was found that different companies have different ways of evaluating quality costs. Some of them only evaluate refund costs. Figure 45 shows the quality costs (as a percentage of turnover) in those companies that evaluate or estimate them. It is interesting to notice that 91% (65+26) of companies referred to have less than 10% quality costs.

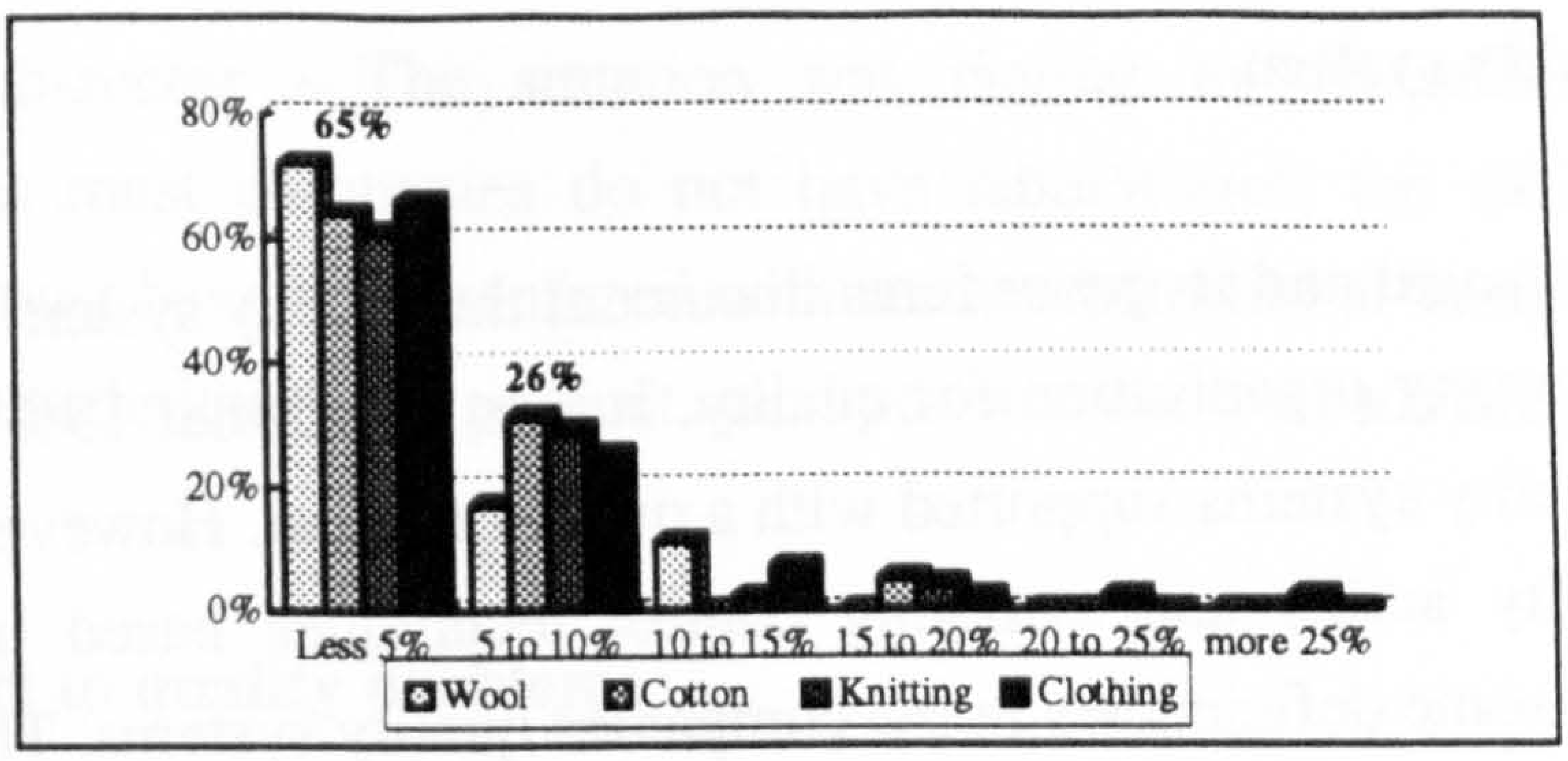

Figure 45 - Quality costs (% of turnover)

Figure 46 show the quality costs scenario for the companies of each sub-sector by company size. The differences between sub-sectors are evident:

- *Wool sub-sector* - Only 29% of companies evaluate quality costs. For these companies quality costs included mainly non-quality costs: scrap, defects and rework. Most companies (70%) had less than 5% quality costs.
- *Cotton sub-sector* - A significant number of companies (46%) evaluate quality costs. Most companies (67%) had less than 5% quality costs.
- *Knitting sub-sector* - 38% of companies evaluate quality costs. In general, companies referred to have more quality costs than wool and cotton sub-sectors (59% of companies referred to have less than 5% quality costs).
- *Clothing sub-sector* - The situation is similar to the knitting sub-sector. 42% of companies evaluate quality costs, and most companies (65%) had less than 5% quality costs.

If this scenario reveals the reality of the industry, one can conclude that the inquired companies presented good conditions to compete with low costs.

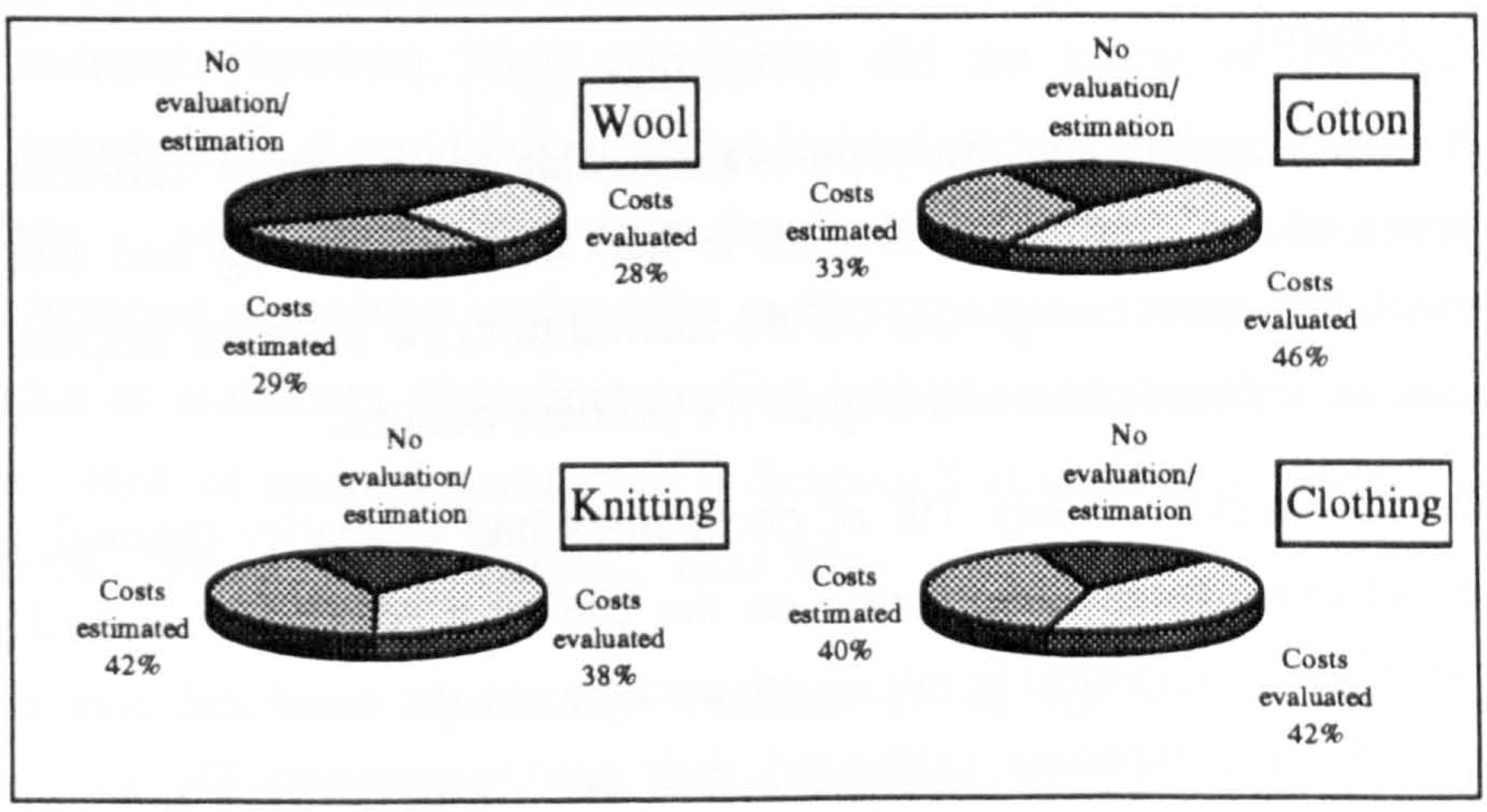

Figure 46 - Quality cost evaluation per sub-sector

5.1.11. Quality system

The quality manual and its procedures document the quality system and it suggests an image of company organisation for quality. It was found that 19% of the companies have their quality systems supported with a quality manual. However, the weak use of internal quality audits and sampling control techniques based in statistical tools demonstrates some deficiencies in the companies quality systems. The validation done in the quality audits confirms the supposition that some manuals were not effectively implemented. Figure 47 shows the situation found for the main requirements of the quality systems.

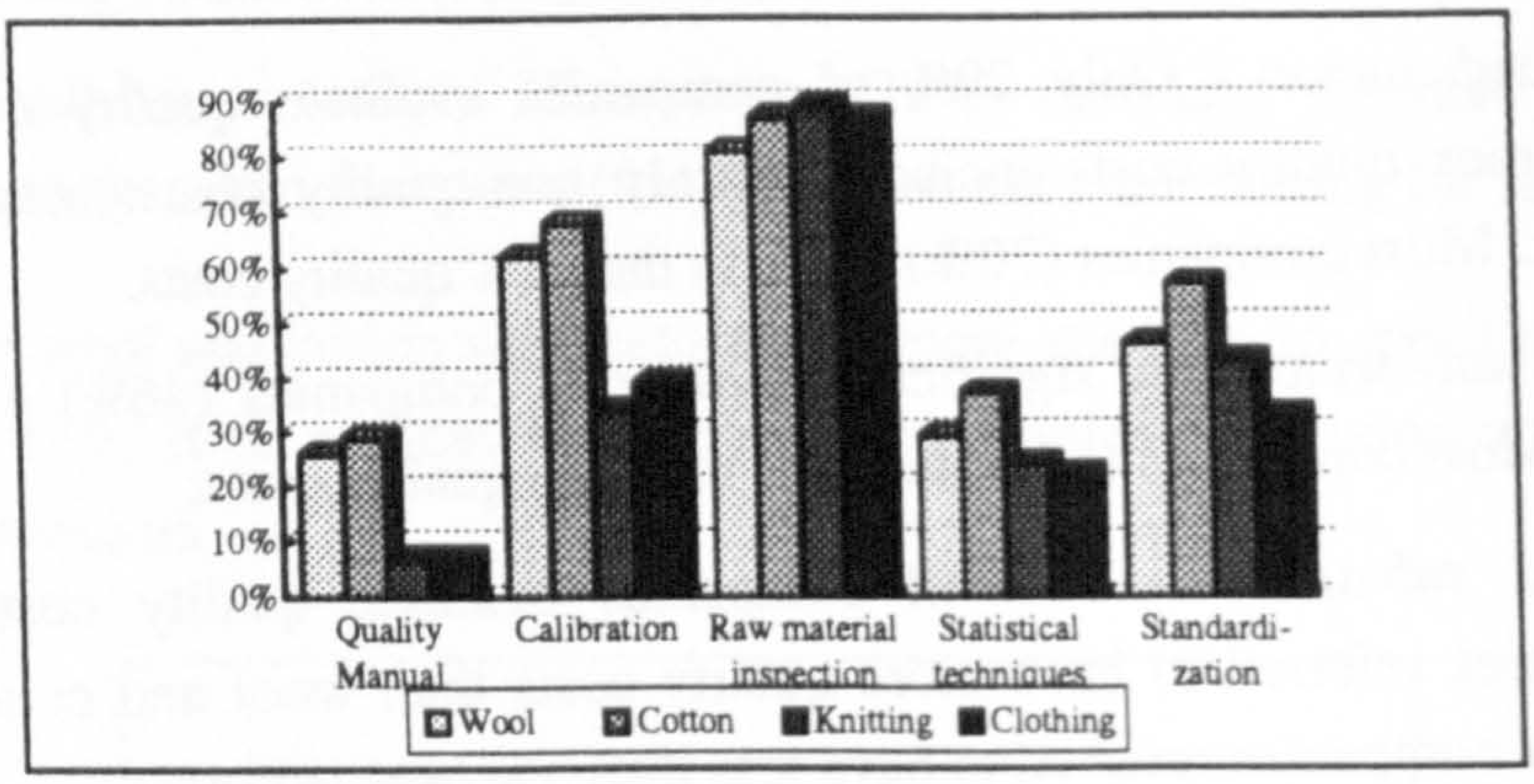

Figure 47 - Organisation for Quality

The situation in the different sub-sectors presents some particularities, namely:

- *Wool sub-sector* - 26% of companies had a quality manual, 62% had their measuring and test equipment calibrated, and most companies (81%) carried out raw material inspection. Only 29% of companies used statistical techniques for process control.
- *Cotton sub-sector* - The situation was similar to the wool sub-sector: 28% of companies had a quality manual, 67% had their measuring and test equipment calibrated, and most companies (87%) carried out raw material inspection. 37% of companies used statistical techniques for process control.
- *Knitting sub-sector* - Only 7% of companies had a quality manual. However, a number of companies commented on the use of a set of diversified procedures. The use of test equipment is not so advanced as in the wool and cotton sub-sectors - only 33% of companies calibrated their test equipment. The use of statistical techniques and product standards was not well advanced either.

- *Clothing sub-sector* - The situation was similar to the knitting sub-sector. However, as most companies do not have laboratories, the calibration of test equipment must have been confused with some other kind of verification. The use of statistical techniques and product standards was not well advanced.

5.1.12. Support to quality problems

Most companies solve their quality problems with external institutions. "Suppliers" (63%), "universities" (34%) and "technical associations" (30%) were considered the best external institutions to solve problems with quality. This situation suggests that there are good customer-supplier relationships. The scenario is similar to all sub-sectors and company size.

5.1.13. Conclusions

The answers to the questionnaire suggest a general feeling that quality is an important industry priority, but most companies have not started quality implementation projects. These results are consistent with the findings of other surveys carried out in different countries and industrial sectors [FOL85, MAC92, ALL91].

Most companies recognised quality techniques as having the biggest impact on final product quality. A significant percentage (60%) refers to quality as a very important issue, but many of them have not implemented quality awareness programmes.

Large companies tend to be more aware for quality management principles. It was found that 19% of the companies had their quality management system supported with a quality manual. However, most companies did not know or understand quality assurance principles and standards, namely: lack of understanding of quality assurance requirements - sometimes they were supposed to mean product requirements; confusion between inspection and quality audit activities - many companies indicated quality audits as indicators of product quality; lack of understanding of the meaning of calibration - 60% of audited companies indicating that inspection, measuring and test equipment was periodically calibrated, were false.

"Financial factors" were generally considered as the main obstacles to the development of textile industry (65%). The "capacity to deliver on time" and "prices not competitive" are other important obstacles. The "competition of low labour cost countries" was considered very important or important by 83% companies, as one of the main obstacles to success. "Training" and "external economical factors" were also considered as very important or important.

Most companies considered quality as an important mean for the improvement of productivity (85% of answers indicated quality as very important). "Automation and technology", "planning and organisation", and "training" were also considered preferred factors. Quality was also considered a significant way for reducing costs (80% of answers indicated quality as very important). Other factors like "technology", "improvement of manufacturing processes", "training" and increasing the level of "motivation" were also considered.

For the improvement of quality, all factors were indicated as very important or important, namely: "training of employees", "manufacturing process control", and "equipment improvements".

The knowledge of quality costs is not well developed. Most companies do not evaluate them, or estimate extremely low values (less than 1% of turnover). Another major conclusion concerns the low number of quality managers who had specific training for quality.

This analysis allowed me to identify four main sub-sectors in the textile industry. In addition, it revealed that the wool and cotton sub-sectors are more advanced than the others in terms of organisation for quality. However, this analysis suggested some doubts and the data collected required validation. The next section presents the results of the audits carried out to validate the previous analysis and collect additional data.

5.2. Results from the audits

5.2.1. Characterisation of the sample of companies audited

After the treatment of the questionnaires, sample companies were selected for the in-company work. The purpose was to validate the previous analysis and collect additional data. Thirty companies were visited, distributed in the four main sub-sectors. These companies were statistically selected with the help of some criteria, namely:

- sub-sector size,
- sample size of the companies that answered the questionnaire,
- geographic location,
- company size (in terms of number of employees and turnover),
- destiny market of products (internal/export),
- kind of products manufactured,
- kind of technology available,
- level of organisation for quality.

The thirty companies selected for the in-company work were distributed in the following sub-sectors:

Sub-sector	Number of companies audited
Wool	6
Cotton	8
Knitting	7
Clothing	9

The distribution of the companies in the other criteria is presented in the following Table:

Number of employees		Turnover		Market		Organisation for quality	
Less 50	1	100 to 299	4	Internal	9	Quality manual	10
50 to 99	3	300 to 499	5	Export	17	Calibration	20
100 to 199	8	500 to 999	5			Raw material inspection	28
200 to 499	13	More 1000	12			Statistical techniques	19
500 to 999	2						
More 1000	2						

The sample of companies selected follows closely the spectrum of the distribution of each sub-sector in the country. The sample of the Wool sub-sector companies were located in the central region of the country and the Cotton sub-sector companies were mainly located in the northern region. Knitting and Clothing sub-sector companies were spread in the centre and north of the country. The majority of the companies audited had 100 to 500 employees and their turnover was greater than 500 million Ptes. In general, two thirds of the companies audited exported more than 50% of its production (in the case of the clothing companies this value amount to 75%). In the organisation for quality criteria, one third of the companies seemed to have some kind of organisation, one third seemed to have a partial system of organisation, and the others appear to have only a reduced system of organisation for quality. The purpose of these criteria was to obtain a broad spectrum of different company scenarios.

This survey was carried out using typical procedures from quality audits. The objective was to understand and characterise the philosophy and working methods used in each company. Another reason was to validate the data supplied in the questionnaires. Quality assurance standard ISO9000 was used as a systematic methodology to assess the companies quality systems and provide a way of comparison between different companies, without dependence on its size.

5.2.2. Example of a quality audit

The audits were performed informally and in many cases the people involved were unaware of its existence. The next three pages present a typical example of a quality audit carried out in the companies. This report is a resume of main findings. It should be complemented with the checklist presented in Annex 4.

Two systems of categorising deficiencies were used: qualitative and quantitative. The approach presented in this report is mainly qualitative. For each particular company, a comprehensive report was written. It included all observed situations and the deficiencies found were divided in three categories: *unacceptable* (a quality system requirement is missing); *conditional* (a quality system requirement/procedure is not documented); *acceptable* (a minor deficiency, no critical fault in the system).

AUDIT REPORT

Company: ABC

Company representatives:	Title:
• Mr A	Managing director
• Mr B	Technical manager
• Mr C	Quality manager
• Mr D	Laboratory manager

Number of employees: 473

Turnover: 1900 MPtes

Kind of final product: Fabric

Production capacity: 100.000 meters/month

Technology available:
office automation
computerised production planning and control
modern equipment
CAD/CAM

Summary of results:

Number of deficiencies:
Unacceptable: 26
Conditional: 20
Acceptable: 5

Scoring level: 3

Deficient requirements:
Quality system
Purchasing
Test equipment calibration
Inspection and testing

Main problems found (general considerations):
Training
Effective use of technology
Absenteeism
Prices

Requirements	Operating	Deficiencies	Categ.
4.1 Management responsibility	• Quality policy is documented • Organisational charts are documented • Responsibilities and authorities are defined and written • The quality function has direct access to top management	• The quality policy is not displayed and spread by all departments • Quality objectives are not clearly defined • Management representative is not appointed • There are not records of management review	CO CO UN CO
4.2 Quality system	• There is a Quality manual • Procedure for manual review (period of revision: 1 year), and responsibility for issuing and updating defined • Procedure for control and distribution of quality manual copies • Procedure for numbering pages and chapters	• The quality manual is not updated, and it is not completely implemented • Quality manual does not state which standards applies • Copies of manual are not numbered • Responsibility for quality manual review is not defined • Quality cost are not evaluated There are not procedures for: • Document control • Control of non-conforming product • Corrective actions • Handling, storage, pack. & delivery • Internal quality audits • Training • No procedures for quality costs	UN AC AC UN CO UN UN UN CO UN UN UN
4.3 Contract review	• There are records of most contracts	• No procedure	CO
4.4 Design control		Not applicable	
4.5 Document control	• There is a master copy of all documents	• There are no procedures for document control • Responsibility for document control, issuing and amending is not defined • The codification system is not documented • Some documents (test methods and instructions) were not signed, and dated • There are no distribution lists of documents	UN UN CO CO UN
4.6 Purchasing	• Quality certificates of some items are requested to suppliers • Each item has a list of general suppliers	• No documented procedures for the selection and evaluation of suppliers • There are no lists of qualified suppliers • Purchasing forms do not include technical specifications (only commercial reference is included) • No records	UN CO UN UN
4.7 Purchaser supplied product		Not applicable	
4.8 Product identification and traceability	• Products are identified, from reception to production, storage and delivery	• The identification method of products is not clearly defined in the quality manual	AC

Requirements	Operating	Deficiencies	Categ.
4.9 Process control	• There is a maintenance plan for critical equipment • Records of inspections are available	• Lack of capability studies • Lack of written operating instructions in the workstations • Lack of a preventive maintenance programme; there are no documents to describe how to operate some equipment	CO CO UN
4.10 Inspection and testing	• There are procedures for testing and inspection of purchased products, work-in-process and final products • Documents available in the textile laboratory: test methods, standards, operating instructions and calibration instructions • Records available	• Lack of inspection and testing instructions in the workstations • Lack of coordination between sampling analysis and the production follow-up • Quality plan not documented • Records of tests do not show values to obtain	CO UN UN AC
4.11 Inspection, measuring and test equipment	• Modern and adequate equipment • Operating instructions available • All the equipment has operating manuals	• Insufficient laboratory space and inadequate environmental conditions • There are no calibration procedures for most measuring and test equip. • There are no calibration plans • Most measuring and test equipment is not calibrated	UN UN UN UN
4.12 Inspection and test status	• There is a procedure for the inspection and test status • Authority for applying and removing inspection and status labels are defined		
4.13 Control of non conforming product	• Non conforming products are identified and segregated in special areas	• There are no procedures for disposition and review of non conforming product • Responsibility for analysis and control of non conforming product is not clearly defined	CO CO
4.14 Corrective actions	• Product submitted to corrective actions need Quality Control approval	• There are no procedures for corrective actions • There are no procedures to investigate the non conforming causes • Responsibility for implementation of corrective actions is not clearly defined • No reports to top management	CO CO CO UN
4.15 Handling, storage, packing, and delivery	• There are adequate practices for handling, storage, packaging and delivery	• No documented procedures	CO
4.16 Quality records	• Quality records are maintained	• There are no documented procedures for: identification, collection, indexation, filing, and maintenance • Retention times are not clearly defined in the quality manual	UN AC

Requirements	Operating	Deficiencies	Categ.
4.17 Internal quality audit	• There is a procedure for internal quality audits • There is an annual plan for internal quality audits in the quality manual	• There are no records of internal quality audits • The procedure is not implemented and needs clarification	UN CO
4.18 Training	• Training courses have been carried out • There is an annual training programme	• There are no procedures for identifying training needs • There are no records of individual training	UN CO
4.19 Servicing		• There are no documented procedures to identify customer requirements, needs and satisfaction	CO
4.20 Statistical techniques	• SPC, control charts by variables, and sampling plans are being used in the reception and final inspection • Instructions are available	• Statistical techniques are not clearly described in the quality manual	CO

5.2.3. Main findings

The analysis of the audits provided the following findings:

Management responsibility

Almost all the analysed companies had clearly identifiable organisational deficiencies. Eight companies (26%) had formulated a quality policy, but only two had promoted this policy with any kind of documents within its premises. However, twenty companies were motivated for the introduction and implementation of a quality system. The reasons given for that were related to cost reduction and customer and market pressures. All companies had organisational charts but in some cases they were not real or sufficient detailed (ex: departments performing quality functions did not appear; sometimes it was not possible to understand the functional and hierarchic interrelationships). The majority of the companies had a quality function or department and in 18 companies (60%) there was a manager for the quality function, but in six cases they shared these functions with others (particularly in the production area). Eight companies appointed a management representative responsible for the implementation and maintenance of their quality systems. In no case did we find records of management review.

Quality system

Quality system requirements may be understood either from the point of view of a customer requirement (that the manufacturer shall assure) or from the point of view of the manufacturer (advantages in formalising an activity). The core documents of a quality system are the quality manual and its procedures. They are vital for a quality system certification. These documents cannot be viewed as bureaucratic overheads. Their function is to formalise common practices, assuring a dynamic and homogeneous action of the working environment. They are a communication vehicle inside the company and necessary for the implementation of a total quality management system. A quality system is a management system. It should be efficient. The quality system procedures should help people and not be felt by them to be unnecessary and difficult to maintain.

Quality Manual - The quality manual documents the company quality programme. It specifies the quality policy, practices and organisation and formalises top management commitment for the quality process. In any quality system assessment, the analysis of the quality manual is a basic and key point. Therefore, the preparation and maintenance of the manual should be done with special care. In the thirty companies visited, only six demonstrated the existence of quality manuals (20%), but two of them had not been implemented. This situation reflects the finding that there was a need to put more effort in the development and documentation of the quality systems.

Inspection and test plans - The inspection and test plan documents, when and where the inspection and test of the characteristics of an item should take place. In general companies carried out inspection and testing but only a few companies (27%) had formalised their inspection and test plans.

Procedures - The procedures describe inter-related tasks and activities. It must specify working practices, its sequences, inter-relationships and means of control. They should be clearly written and document quality system requirements.

In general the companies used good working practices. However, these practices were not documented in the form of written procedures. Only a few companies had written procedures:

- 20 companies had specifications for finished products,
- 17 companies had specifications for bought out raw materials
- 12 companies had specifications for inspection and testing
- no procedures were found for subcontracting, contract review, design and development of new products, packaging and expedition.

It was clear that all the companies knew the meaning of certification and were acquainted with quality assurance standards ISO9000 (or at least they knew them). However, none of the companies visited had its quality system certified, but four companies were working for the certification in the medium term (2 years).

Contract review

This requirement is mainly directed to unique products. However, it can be considered in companies manufacturing their own products. No written procedures for this quality system requirement were identified in the audited companies.

Design control

Product design and development are driven by international fashion. Companies use their individual experience for the design of new products. However, only six companies had historical data recorded to support this activity and there was no evidence of written procedures for design control. Most companies (73%) used CAD systems for product design and development, so good design data recording is potentially available. This requirement is not mandatory for the ISO9002/3.

Document control

For setting up a document control system, the first step is to identify the documents needing to be controlled. There are documents that need no control. Those related to the quality system and quality itself do need it. This was one of the most difficult and systematically deficient requirements identified. Only a few companies had even rudimentary written procedures for document processing, control, revision and substitution.

Inspection, measuring and test equipment

This requirement was found to be one of the most difficult to cope with, because specific technical knowledge is necessary along with detailed managerial procedures. However, fourteen companies (47%) had adequate test equipment and its calibration status was evident. Six companies had adequate test equipment but it was not systematically calibrated. The remainder eventually used external laboratories. Only a few companies had written procedures for calibration and maintenance of equipment and for testing activities.

Purchasing

Seven companies had formal procedures for assessing and qualifying their suppliers. Most companies did not have an updated list of suppliers with historical data about former supplier performance. Only six companies included systematic quality specifications and requirements for bought-in materials in purchasing orders. The remainder did not have template forms to assure a systematic practice. It was found that in most cases the definition of the responsibilities for assessment was a delicate matter (a purchasing/quality conflict usually existed).

Inspection and test status

Inspection and test status may be identified in any convenient way (from an inspection record only, to a labelled and segregated area). Sixteen companies had identification systems to ensure that non-conforming material did not pass into production: red stickers (8), special documents (6) or segregation in an isolated area (2). A similar situation was found for finished products.

Inspection and testing

Inspection and testing records provide evidence that quality has been achieved. For that purpose, companies should show, not only the obtained values, but also the values to be obtained and the acceptance criteria. This was a deficiency systematically noted.

In 8 (26%) companies operating laboratories, most of the tests were performed according to national/international standards. In most cases the records showed the results, not the acceptance criteria.

Most companies inspected incoming goods on a visual inspection basis: 22 (73%) did it by sampling, 4 (13%) inspected all items and the remaining did it occasionally. For final inspection most companies inspected the product on a 100% basis, but only 8 companies had records for this activity and 50% of the companies did not have final inspection plans or checklists.

Product identification and traceability

It was found that most companies identified their products. Ten companies (33%) used coding systems for identification of products, but no company was found that referred to it in the quality manual. It was difficult to trace the products during the production cycle. Traceability is not considered a critical requirement (with some exceptions) in this kind of industry.

Handling, storage, packing and delivery

Only one company presented documented procedures covering storage for raw materials, unfinished products and final products (for identification of items in stores and issuing materials from stores). Most companies presented adequate means of handling, storage and packing, but without documented procedures.

Process control

Most companies used auto-control but (with the exception of four cases) it was found that employees do not have the right tools available to them for this purpose (testing equipment or written instructions). In most situations quality inspectors received verbal instructions. In twelve companies the process control was assured by sophisticated electronic control systems installed in the manufacturing equipment, but only 8 companies used control charts.

13% of companies used statistical process control (SPC). It was found that the main reasons for the non-adoption of SPC were: 1. lack of understanding or awareness of SPC techniques (60%); 2. awareness of SPC techniques, but never tried (20%); 3. tried SPC techniques and found them unsuitable (7%).

Twelve companies (40%) used some kind of diagnostic tools as quality improvement techniques: Pareto analysis, histograms, fishbone diagrams, motivation programmes and quality circles. This is an important deficiency that should be addressed. Analysing and diagnosing problems affecting quality is a step forward for the improvement of quality systems.

Quality records

Twenty companies (67%) recorded data from quality control activities and maintained them for a specific period of time. However only 7% presented quality record procedures defining how, where, and by whom quality records should be maintained.

Control of non conforming product

Usually, nonconforming products were identified, although the nonconformities were not documented. The practice adopted was reprocessing the non conforming products, but it was not supported with written procedures. In addition, reclassification of products was not done (in 27% of companies) and responsibility and authority for review and disposition were not clearly defined.

Internal quality audits

Internal quality audits are a powerful tool to maintain the quality system. They aim at verifying quality activities and determining the effectiveness of the quality system. In general, companies did not perform internal quality audits. Only companies that had a quality manual performed internal quality audits but only one had documented procedures.

Corrective actions

This requirement is considered one of the most indicative of the effectiveness of the quality system. No process or system can be considered as under control if it is not possible to identify the objectives to be attained, the control activities (inspection and test activities, internal quality audits), and constant corrective actions. Figure 48 gives a general idea of the interrelationships between various activities and functions.

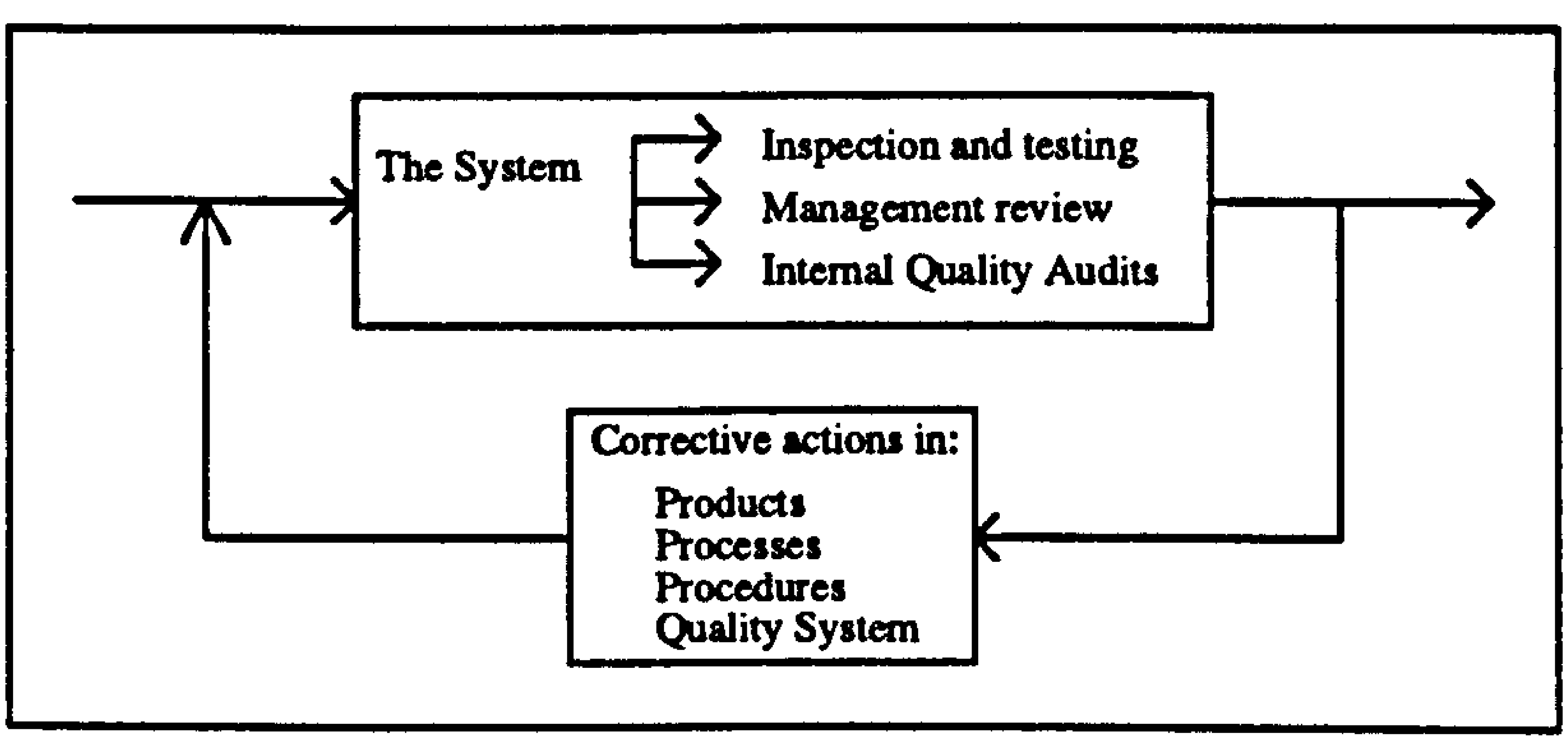

Figure 48 - Interrelationships between activities and functions

To evaluate this requirement, the most suitable way is to verify the existence of corrective action procedures and records. Only 8 companies (26%) had written corrective action procedures to deal with rejected material, non-conformities or other quality problems. However, only two companies sent periodic quality reports to top management.

Quality costs

The existence of quality services in companies should provide benefits and it has a cost that must be known by management as well as non-quality costs of defective products. The knowledge of quality related costs is recognised as a powerful management tool. Unfortunately, quality costs were largely unknown. Fifteen companies (50%) evaluate costs of refund but only 3 calculated quality costs in a more systematic way.

Training

All the companies had trained its personnel but only 12 run specific quality control courses. Companies had neither documented procedures for identifying training needs nor annual planning for training. Records of training courses and qualified people were available in most companies.

Concerning the qualification of the quality personnel, the scenario found was the following: good knowledge of general quality control techniques (15%); some knowledge of quality control techniques (30%); some knowledge of specifications and poor knowledge of quality control techniques (30%); only some knowledge of specifications (25%).

After sales servicing

There was a general lack of documented procedures to identify customer requirements, needs and non satisfactions. This requirement is not mandatory for the ISO9002/3. Even for ISO9001 procedures are only required when servicing is specified in the contract.

Statistical techniques

Only 13% of companies used statistical techniques (SPC) and agreed established procedures. None of the remaining companies used statistical techniques either for verifying the process capability or for product characteristics. Two companies used the MIL-STD-105 in receiving inspection, and reported the results of control of some process variables through a histogram of frequencies.

5.2.4. Conclusions

After this research in thirty companies, a ranking was done in a scale of five levels. The level one represents a company in the very first stage of development of its quality system. The level five corresponds to a company that already has its system working and in a status which would allow certification. Figure 49 shows a global view of the level of Organisation for Quality.

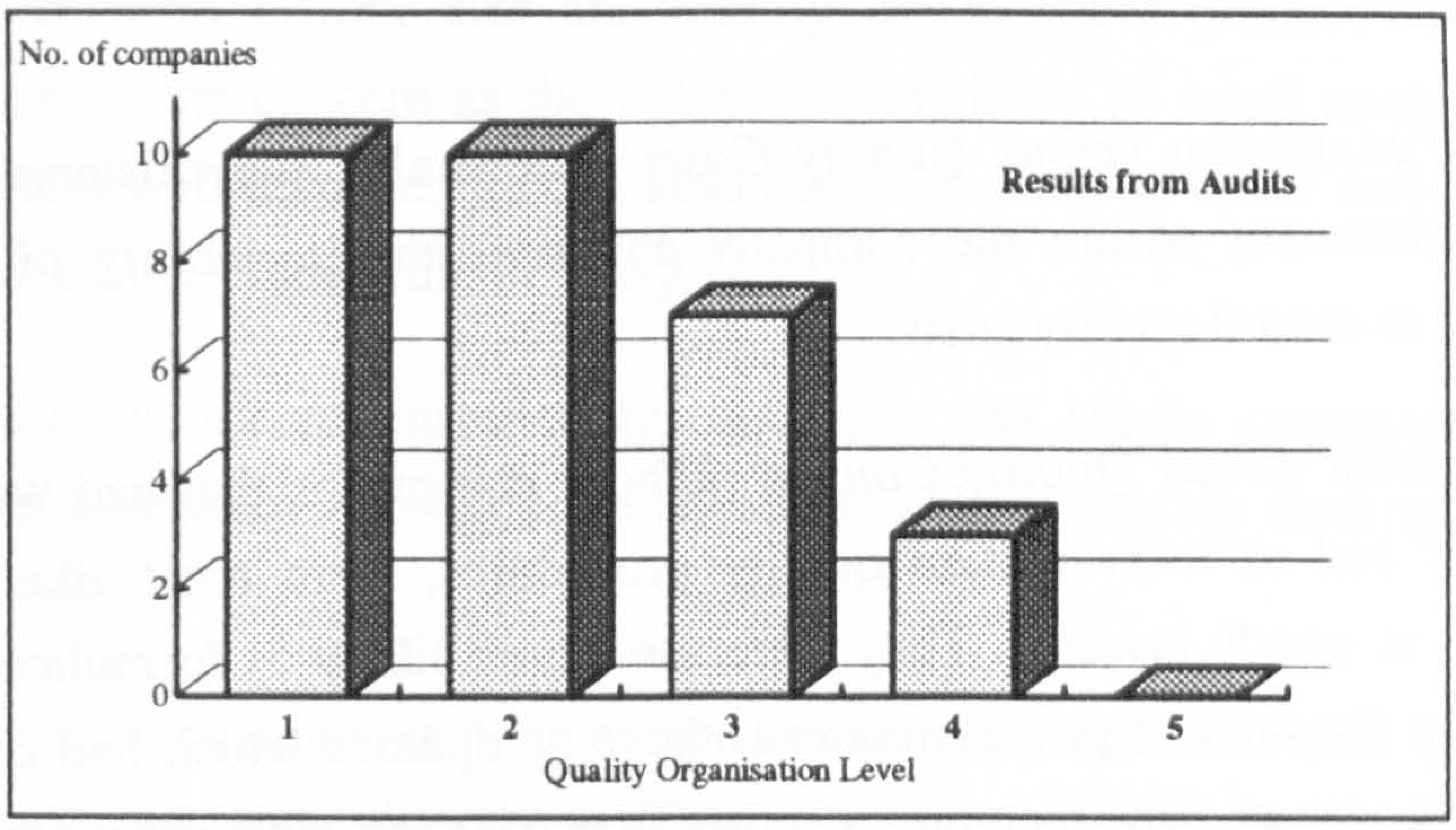

Figure 49 - Level of Organisation for Quality

This study embraced all the sectors of the Textile and Clothing Industry. It revealed that the wool and cotton sub-sectors are more advanced than the others in terms of quality control. This situation can be explained in face of the rigorous specifications and quality requirements imposed by customers. Suppliers are pressed to control their products and to have an organisation that can prove a good quality environment. These include specifications and conditions for inspection and testing and even test equipment to be used.

5.2.4.1. The interrelationships between the four aspects of quality

Strong interrelationships were found between the four aspects of quality systems - quality organisation, quality system, quality control and quality costs (see Table 21):

Quality Organisation versus Quality System - Those companies which possessed a quality management representative were more likely to own either a quality manual or have written quality procedures. Similar relationships were also apparent between the existence of a company quality department and the possession of a quality manual and knowledge of quality assurance standards.

Quality Organisation versus Quality Control - The only associations to show here are those between the existence of a quality department and the most frequently used method of controlling the quality of production processes, and verifying the correctness to specification of finished products. It appears that those companies that have set up separate quality departments tend to prefer the usage of SPC techniques at these stages.

Quality Organisation versus Quality Costs - Generally, the existence of a separate quality department within the company enhances the possibility of that company attempting to record quality costs.

Quality System versus Quality Control - Those companies that had written a quality manual, or had at least written quality procedures, were more likely to use SPC techniques at goods inwards. They were also more likely to formulate vendor rating schemes. In the area of process control, those companies which had quality manuals favoured the use of SPC techniques rather than 100 per cent inspection. The chances of a company using SPC for finished goods was also increased if they had some form of quality manual in their possession. As expected, the possession of a quality manual, or some form of formal written procedures, results in generally better quality control procedures.

The knowledge of quality assurance standards seems to increase the chances of SPC being used at goods inwards, of vendor rating schemes being used, and of the reliability of products being monitored. Although there was a small number of companies carrying out quality audits, those companies tend to prefer the use of SPC during process control and at final inspection. In addition, vendor rating schemes are more likely to be used by those companies that have laid down specifications for bought-in materials, and companies that have specifications for finished products tend to make greater use of SPC during process control.

Quality System versus Quality Costs - There is a strong positive relationship between the existence of a quality manual and the recording of quality costs, and knowledge or registration to quality assurance standards has a similar effect.

5.2.4.2. Sub-sector particularities

The performance of the companies quality systems appears to be influenced by the sub-sector of the company. Cotton and knitting sub-sectors present companies with better global quality systems. In addition, as one might expect, the larger the factory site, the better the quality system. From national statistics, only 14% of textile companies employ 200 or more people (in our sample it represents 30% which indicates that many small companies did not answer the questionnaire). Hence the relationship between factory size and quality management practices in the textile industry causes some concern as the industry is made up of small companies, which clearly have less well-managed quality systems. This could go some way to explaining the relative decline of the textile industry.

The importance of the organisation for quality in the textile companies audited is recognised as a definitive competitive advantage. However, my findings suggest the following:

- There is no evidence that the companies formally establish their quality policy, organisation and objectives. This situation affects the establishment of permanent and planned actions to assure the best quality at the minimum internal cost,
- Final product quality satisfies customers. However, it depends on higher number of inspections, and higher costs,
- The use of laboratories (inspection and testing) for quality control is done but with some deficiencies in terms of test equipment calibration and maintenance,
- The use of quality assurance procedures is not well advanced. Most companies follow good manufacturing and quality practices but many companies use a quality system which is not supported with quality manuals or other documentation,
- Regarding the specific characteristics of the Portuguese textile industry, the level of the Quality Assurance standards to apply should be the ISO9002,
- The quality costs are not evaluated properly. It is difficult to justify the implementation of a documented quality system from an economic point of view. It depends only on a strategic company policy.

The results from questionnaires and audits provided a deep understanding of the textile industry. A large quantity of data was collected. The first and second sections of this chapter presented mainly quality related data and its analysis. The following section will present how the complete set of data collected was used in modelling for Lean Manufacturing.

5.3. Results from the model application

5.3.1. Quantification of model variables

The work carried out in the auditing phase provided quantification of the model variables. Tables 18, 19, 20 and 21 present the results from the quality assurance system assessment. The model variable Q1 was calculated as the average of the four quality blocks: organisation, system, control and costs. Table 19 shows the global data of all the audited companies organised by ascending order of performance. From Table 20 it is clear that cotton and knitting sub-sectors have companies with better quality systems. The cotton sub-sector presents a group of companies with better quality assurance systems. Quality control has been the area where companies have been putting more efforts. The use of sophisticated laboratories, specially in the cotton sub-sector, is a means of quality failure prevention. However, companies are shifting their concerns from the quality control aspect to the quality management and organisation as a way to prevent future quality problems. In general, the evaluation of quality costs is not very well developed. It seems that managers are not aware (or they have not the right knowledge or tools) of the importance of quality costs as a vital management tool. However, there is always a high correlation between the quality assurance system variable (Q1) and all the other quality variables (see Table 21).

Table 22 presents the results from the flexibility assessment. The companies from the knitting sub-sector appear to be more flexible in all the considered dimensions. The clothing sub-sector is the second most flexible, but design flexibility is not a strong characteristic. The general small size of knitting companies suggests that small companies are more flexible. In addition, we can conclude that young companies are more flexible than traditional companies, like those existing in the wool and cotton sub-sectors. In terms of people flexibility, this explanation can be complemented with the existence of a low level of education and training in traditional sub-sectors. In fact, a higher level of education and training is recognised as being able to improve people flexibility.

Table 23 is concerned with the assessment of anthropocentric issues. Knitting and cotton sub-sectors present the best performing anthropocentric issues. The clothing sub-sector is dealing with important problems regarding this issue. It is even more evident if we look at the absenteeism level in this sub-sector. In general, there is a relatively high performance of anthropocentric issues in the companies audited. However, it was found that in the same sub-sector there are companies in different levels (it can be seen in the statistical analysis - Table 27).

Tables 24 and 25 show the level of performance of technologies and production techniques in the audited companies. Knitting and cotton sub-sectors demonstrate a better use of technologies and production techniques. The wool sub-sector is identified as an old sector that needs to be updated with new technologies and production techniques. The use of CAD/CAM systems in this sub-sector is still incipient. In general, there is an adequate use of technologies with the exception of their integration in a CIM environment. In what concerns production techniques, it can be seen that group technology and just-in-time are not very popular among those sub-sectors where they could be particularly applied. There is an increasing interest in MRP, maintenance management and computerisation of information systems.

All these model variables have a value between 1 and 5, according to the rating calculated from the use of the checklists presented in Annexes 3, 4, 5 and 6.

Table 26 presents a resume of all the main model variables and Table 27 presents a statistical analysis of all the model variables. Table 26 is organised by sub-sector and companies in each sub-sector are ranked by quality assurance system. A company with a higher index (ex: Co.8) has a better quality assurance system in its sub-sector. Notice that the ALP value is calculated as the average of all the variables (see sections 3.4.3 and 5.3.2), as they are presented in Table 28. This table is the result of a transformation of objective variables (the real figures were transformed in a 1 to 5 scale), as it was explained in section 4.1.5.

The analysis of how these variables are correlated is an important step to understand the situation. Correlation matrixes between all the model variables for each sub-sector were developed. Table 29 is a correlation matrix for a global correlation among model variables.

The analysis carried out provided the main following comments:

1. *Quality Assurance System (Q1) versus Material Scrap (Q2)* - in general Q1 has a medium negative correlation[1] with Q2. It is interesting to notice that this correlation is slightly higher for those sub-sectors with less developed quality assurance systems.

2. *Quality Assurance System (Q1) versus Failure Costs (Q3)* - as expected there is also a significant negative correlation between these variables. However, knitting and clothing sub-sectors present a low level of correlation (≈0.33). This low correlation can be due to the fact that these sub-sectors are very young. In addition, those companies that started with the implementation of quality systems only recently have been doing it.

3. *Quality Assurance System (Q1) versus Quality Costs (Q4)* - these variables are very correlated. It is also interesting to notice that the sub-sector with better Q1 is the one that spends more on quality costs (which include prevention and appraisal costs).

4. *Quality Assurance System (Q1) versus Delivery variables (D1, D2, D3)* - the knitting sub-sector presents the better timeliness of delivery (D1) and delivery lead time (D2). Excepting the variable average lateness of delivery (D3), there is no special correlation between variables. This unexpected low correlation is not equal for all the sub-sectors. These variables depend on the characteristics of each sub-sector. In many situations, late supplies of raw material are responsible for late deliveries. However, it seems that, the better the quality assurance system, the lower the average lateness of delivery.

5. *Quality Assurance System (Q1) versus Cost issues (C1, C2, C3, C4)* - Most companies in all sub-sectors appear to have too much raw material in warehouse for long periods. In what concerns work-in-process, a similar situation exists. However, the knitting sub-sector demonstrates a significant awareness for the elimination of excessive raw materials and work-in-process. This is reflected in a higher value added per employee in this sub-sector, as well as in the clothing sub-sector. The reason for that may be explained because wool and cotton companies usually have to buy raw materials in international markets. These markets have seasonal characteristics as they depend on the period of the year that the wool is

[1] A negative correlation means that the proportionality among two variables is characterised by a negative slope of the regression line defined by the observed distribution.

cut or the cotton is harvested. This situation is responsible for the creation of large warehouses, where raw material is waiting for several months.

The correlation between Ql and the cost issues is not evident from Table 29 (only the value added per employee and the production costs per employee present significant correlation with Ql). However, strong correlation factors exist when we consider the individual sub-sectors. This is due to different business characteristics of each sub-sector.

6. *Quality Assurance System (Ql) versus Flexibility (F)* - there is a high correlation factor with flexibility, mainly in the wool (0.79) and cotton (0.87) sub-sectors. Design flexibility is particular correlated with Ql which means that special care must be addressed to this variable in defining the new quality requirements for Lean Manufacturing (see Chapter 4.2).

7. *Quality Assurance System (Ql) versus Time related issues (T)* - knitting and clothing present better performances of time related issues. This, again, is due to the specific business characteristics of each sub-sector. In general, there is relatively low correlation between the variables. Although this situation exists, a trend in the reduction of the time related variables values was identified. In fact, in sub-sectors with better quality assurance system (as the case of cotton) it is possible to identify a significant correlation with the reduction of setup time (-0.58), time to introduce new products (-0.57) and waste time (-0.61). The correlation with materials residence time in warehouse is not evident because of the reasons explained in 5.

8. *Quality Assurance System (Ql) versus Anthropocentric issues (A)* - for all the sub-sectors there is a high level of correlation (0.71) between anthropocentric issues and Ql. This situation clearly shows how people are important in improving the quality system.

9. *Quality Assurance System (Ql) versus Innovation (I)* - innovation shows also a high correlation (0.75) with Ql. The knitting sub-sector presents a higher number of new products launched per year. On the opposite side, the clothing sub-sector depends on customer orders and customer design. Many companies revealed that they work with customer design. Therefore, the design of new products is not their exclusive responsibility and the amount of new products launched per year can be lower. This situation explains the weak level of design flexibility in the clothing sub-sector, as stated before.

10. *Quality Assurance System (Q1) versus Technology (G)* - as expected there is a high correlation (0.68) between the quality assurance system and technological issues.

11. *Quality Assurance System (Q1) versus Production Techniques (PT)* - there was also expected to exist a high correlation between these variables. The situation revealed in 10 and 11 shows the importance of including technological issues when assessing company performance.

12. *Quality Assurance System (Q1) versus Productivity (PR)* - from a global perspective there is no correlation between productivity and Q1. However, if we consider individual sub-sectors we have the following scenario of correlation: wool 0.48; cotton 0.92; knitting 0.81; clothing 0.38. In addition, after the variables transformation process (in a scale 1 - 5) to homogenise them, a high correlation was found: 0.7 (Figure 56).This scenario suggests that productivity improvements depend on adequate quality assurance systems.

13. *Quality Assurance System (Q1) versus Average Level of Performance (ALP)* - as expected there is a high correlation between ALP and Q1. Considering individual sub-sectors there are still higher correlation factors.

Important correlation between other variables:

14. *Value Added per Employee (C3) versus Technologies (G) and Production Techniques (PT)* - there is a significant correlation between the value added per employee and technologies (0.68) and production techniques (0.66). It is evident that technological issues are playing a determinant role in the increase of C3. But, as it was shown in 5, C3 is also correlated with Q1.

15. *Productivity (PR) versus Cost issues (C1, C2, C3)* - there is a general significant negative correlation between productivity and the cost of raw material in warehouse.

16. *Productivity (PR) versus Flexibility (F)* - productivity has a high correlation with production, material and people flexibility.

17. *Productivity (PR) versus Time issues (T)* - productivity has a significative negative correlation with all the time variables considered.

Finally, there is a high level of correlation of ALP with most variables. This is a natural result that depends on the method of ALP evaluation.

Table 18 - Results from Quality Assurance System Assessment (per subsector)

Quality Assurance	Wool					
	W.1	W.2	W.3	W.4	W.5	W.6
Organisation	1	1	2	3	3	4
System	1	1	2	2	2	4
Control	2	2	1	3	3	4
Costs	1	1	1	1	1	2
QI	1.25	1.25	1.50	2.25	2.25	3.50

Quality Assurance	Cotton							
	Co.1	Co.2	Co.3	Co.4	Co.5	Co.6	Co.7	Co.8
Organisation	1	2	3	3	3	3	4	4
System	1	3	3	3	3	3	4	4
Control	2	2	3	4	5	5	4	5
Costs	1	1	1	1	2	2	3	3
QI	1.25	2.00	2.50	2.75	3.25	3.25	3.75	4.00

Quality Assurance	Knitting						
	K.1	K.2	K.3	K.4	K.5	K.6	K.7
Organisation	1	1	2	3	2	3	4
System	1	1	2	2	3	3	3
Control	1	2	3	3	3	4	4
Costs	1	1	1	1	1	1	2
QI	1.00	1.25	2.00	2.25	2.25	2.75	3.25

Quality Assurance	Clothing								
	Cl.1	Cl.2	Cl.3	Cl.4	Cl.5	Cl.6	Cl.7	Cl.8	Cl.9
Organisation	2	1	1	1	1	2	3	2	3
System	1	1	1	1	1	1	1	2	2
Control	1	2	2	2	2	3	3	3	3
Costs	1	1	1	1	1	1	1	1	2
QI	1.25	1.25	1.25	1.25	1.25	1.75	2.00	2.00	2.50

Table 19 - Results from Quality Assurance System Assessment (per ascending importance)

Quality Assurance	Companies																													
	K.1	W.1	W.2	Co.1	K.2	Cl.1	Cl.2	Cl.3	Cl.4	Cl.5	W.3	Cl.6	Co.2	K.3	Cl.7	Cl.8	W.4	W.5	K.4	K.5	Co.3	Cl.9	Co.4	K.6	Co.5	Co.6	K.7	W.6	Co.7	Co.8
QI	1.00	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.50	1.75	2.00	2.00	2.00	2.00	2.25	2.25	2.25	2.25	2.50	2.50	2.75	2.75	3.25	3.25	3.25	3.50	3.75	4.00

Table 20 - Statistical analysis of Quality Assurance variables

Quality Assurance	Wool Average	6 Comp. StDev	Cotton Average	8 Comp. StDev	Knitting Average	7 Comp. StDev	Clothing Average	9 Comp. StDev	TOTAL Average	30 Comp. StDev
Organisation	2.33	1.21	2.88	0.99	2.29	1.11	1.78	0.83	2.30	1.06
System	2.00	1.10	3.00	0.93	2.14	0.90	1.22	0.44	2.07	1.05
Control	2.50	1.05	3.75	1.28	2.86	1.07	2.33	0.71	2.87	1.14
Costs	1.17	0.41	1.75	0.89	1.14	0.38	1.11	0.33	1.30	0.60
QI	2.00	0.87	2.84	0.92	2.11	0.79	1.61	0.47	2.13	0.87

Table 21 - Correlation between Quality Assurance variables

	Global					Wool					Cotton					Knitting					Clothing				
	Org.	*Syst.*	*Ctrl*	*Costs*	*QI*	*Org.*	*Syst.*	*Ctrl*	*Costs*	*QI*	*Org.*	*Syst.*	*Ctrl*	*Costs*	*QI*	*Org.*	*Syst.*	*Ctrl*	*Costs*	*QI*	*Org.*	*Syst.*	*Ctrl*	*Costs*	*QI*
Organisation	1.00					1.00					1.00					1.00					1.00				
System	0.82	1.00				0.90	1.00				0.93	1.00				0.78	1.00				0.49	1.00			
Control	0.78	0.76	1.00			0.79	0.70	1.00			0.76	0.60	1.00			0.88	0.89	1.00			0.57	0.53	1.00		
Costs	0.67	0.68	0.67	1.00		0.67	0.89	0.70	1.00		0.77	0.70	0.69	1.00		0.68	0.42	0.47	1.00		0.55	0.66	0.35	1.00	
QI	0.93	0.92	0.91	0.81	1.00	0.95	0.95	0.88	0.85	1.00	0.96	0.88	0.88	0.87	1.00	0.96	0.91	0.96	0.64	1.00	0.87	0.77	0.82	0.71	1.00

Table 22 - Flexibility

	Wool						Cotton								Knitting							Clothing								
	W.1	W.2	W.3	W.4	W.5	W.6	Co.1	Co.2	Co.3	Co.4	Co.5	Co.6	Co.7	Co.8	K.1	K.2	K.3	K.4	K.5	K.6	K.7	Cl.1	Cl.2	Cl.3	Cl.4	Cl.5	Cl.6	Cl.7	Cl.8	Cl.9
F1 - Design F.	2	2	3	2	3	4	2	2	2	2	4	4	5	5	2	4	3	3	3	4	5	2	1	2	1	2	3	4	3	3
F2 - Production F.	2	3	2	3	2	2	1	2	2	1	2	3	2	2	3	4	4	5	3	3	4	4	4	4	4	4	2	4	3	3
F3 - Materials F.	2	1	2	1	1	3	2	2	2	2	2	2	2	2	3	4	3	3	3	3	4	2	3	3	2	3	3	3	4	3
F4 - People F.	1	1	2	2	1	3	2	2	1	3	3	3	3	3	3	3	4	5	3	3	4	3	3	2	2	3	2	4	3	3
F	1.75	1.75	2.25	2.00	1.75	3.00	1.75	2.00	1.75	2.00	2.75	3.00	3.00	3.00	2.75	3.75	3.50	4.00	3.00	3.25	4.25	2.75	2.75	2.75	2.25	3.00	2.50	3.75	3.25	3.00

Table 23 - Anthropocentric issues

	Wool						Cotton								Knitting							Clothing								
	W.1	W.2	W.3	W.4	W.5	W.6	Co.1	Co.2	Co.3	Co.4	Co.5	Co.6	Co.7	Co.8	K.1	K.2	K.3	K.4	K.5	K.6	K.7	Cl.1	Cl.2	Cl.3	Cl.4	Cl.5	Cl.6	Cl.7	Cl.8	Cl.9
A1 - Motivation	1	1	3	3	2	4	2	3	1	3	4	3	4	4	2	3	3	5	3	3	4	4	2	3	2	2	2	4	3	2
A2 - Communication	2	2	3	3	3	4	2	3	2	3	4	3	3	4	3	4	3	4	3	4	4	3	3	3	2	2	2	3	3	2
A3 - Training	1	1	2	3	1	4	2	1	3	3	3	4	4	5	2	2	4	5	3	4	5	3	1	1	2	1	2	4	2	2
A4 - Working conditions	3	2	3	4	2	4	2	3	3	4	5	5	5	5	2	3	4	5	3	4	5	4	1	3	2	1	3	4	2	4
A5 - Absenteeism	2	3	3	3	2	3	2	2	2	3	3	3	3	3	2	3	2	4	2	3	3	3	2	3	2	2	2	3	3	1
A	1.80	1.80	2.80	3.20	2.00	3.80	2.00	2.40	2.20	3.20	3.80	3.60	3.80	4.20	2.20	3.00	3.20	4.60	2.80	3.60	4.20	3.40	1.80	2.60	2.00	1.60	2.20	3.60	2.60	2.20

Table 24 - Technologies

	Wool						Cotton								Knitting							Clothing								
	W.1	W.2	W.3	W.4	W.5	W.6	Co.1	Co.2	Co.3	Co.4	Co.5	Co.6	Co.7	Co.8	K.1	K.2	K.3	K.4	K.5	K.6	K.7	Cl.1	Cl.2	Cl.3	Cl.4	Cl.5	Cl.6	Cl.7	Cl.8	Cl.9
G1 - CAD/CAM	2	0	1	1	2	3	1	0	1	2	5	3	5	5	2	4	4	4	3	3	4	4	1	3	1	4	4	5	2	5
G2 - Robotics/automation	3	2	3	3	2	4	3	2	3	3	4	3	4	5	3	2	3	4	3	3	4	3	2	2	1	3	5	3	2	3
G3 - Materials handling	2	1	2	2	1	2	2	1	2	3	4	4	4	5	1	1	2	4	2	2	3	2	1	2	1	2	2	4	2	2
G4 - Warehousing	2	1	2	2	2	2	2	2	2	3	4	2	4	4	1	1	2	3	2	3	4	2	1	2	1	2	1	3	1	3
G5 - CIM/integration	1	1	2	3	1	2	1	1	1	2	3	2	3	3	2	1	3	4	2	2	3	3	1	1	1	1	3	3	2	3
G6 - Equipment	4	2	3	4	3	4	3	2	3	4	4	4	4	5	4	3	4	5	3	4	5	4	3	3	2	3	5	4	3	4
G	2.33	1.17	2.17	2.50	1.83	2.83	2.00	1.33	2.00	2.83	4.00	3.00	4.00	4.50	2.17	2.00	3.00	4.00	2.50	2.83	3.83	3.00	1.50	2.17	1.17	2.50	3.33	3.67	2.00	3.33

Table 25 - Production Techniques

	Wool						Cotton								Knitting							Clothing								
	W.1	W.2	W.3	W.4	W.5	W.6	Co.1	Co.2	Co.3	Co.4	Co.5	Co.6	Co.7	Co.8	K.1	K.2	K.3	K.4	K.5	K.6	K.7	Cl.1	Cl.2	Cl.3	Cl.4	Cl.5	Cl.6	Cl.7	Cl.8	Cl.9
PT1 - Group technology	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4	2	0	2	2	0	0	0	0	3	3	0	2
PT2 - Just-in-time	1	0	0	0	0	2	0	0	0	2	0	2	0	0	0	0	4	5	0	0	0	1	0	0	0	0	1	2	0	1
PT3 - MRP	1	1	2	3	1	3	1	1	2	2	4	3	4	3	1	1	3	3	2	4	3	2	1	1	1	1	2	3	2	3
PT4 - Maintenance Mgt.	2	1	2	2	1	2	1	2	1	1	2	2	3	3	1	1	2	3	1	1	3	1	1	1	1	1	2	2	1	2
PT5 - Work study	2	1	2	3	1	2	1	2	1	2	4	3	4	4	3	2	4	5	3	3	5	3	1	2	1	2	4	4	3	4
PT6 - Layout design	4	2	2	3	3	2	2	3	3	3	3	3	4	4	2	3	3	5	3	4	5	4	2	3	2	3	2	4	2	3
PT7 - Inventory Mgt.	1	1	2	3	1	3	1	1	2	2	4	3	4	3	1	1	3	3	2	4	3	2	1	1	1	1	2	3	2	3
PT	1.83	1.00	1.67	2.33	1.17	2.33	1.00	1.50	1.50	2.00	2.83	2.67	3.17	2.83	1.33	1.33	3.17	4.00	1.83	2.67	3.17	2.17	1.00	1.33	1.00	1.33	2.17	3.00	1.67	2.67

Table 26 - Ranking by Quality Assurance and subsector

	Wool						Cotton								Knitting							Clothing								
	W.1	W.2	W.3	W.4	W.5	W.6	Co.1	Co.2	Co.3	Co.4	Co.5	Co.6	Co.7	Co.8	K.1	K.2	K.3	K.4	K.5	K.6	K.7	Cl.1	Cl.2	Cl.3	Cl.4	Cl.5	Cl.6	Cl.7	Cl.8	Cl.9
Q1	1.25	1.25	1.50	2.25	2.25	3.50	1.25	2.00	2.50	2.75	3.25	3.25	3.75	4.00	1.00	1.25	2.00	2.25	2.25	2.75	3.25	1.25	1.25	1.25	1.25	1.25	1.75	2.00	2.00	2.50
Q2	20	12	20	16	16	10	16	14	20	15	14	13	12	15	18	20	14	5	12	14	10	15	18	19	18	18	18	13	15	14
Q3	25	10	15	13	14	8	12	16	18	12	10	4	9	6	16	10	12	4	14	12	10	18	16	18	25	22	16	17	16	20
Q4	1	1	1	2	1	4	1	2	1	3	6	5	5	7	1	1	3	3	2	3	3	1	1	1	1	1	1	2	1	2
D1	22	14	25	15	19	20	19	8	16	10	8	18	12	14	12	5	6	2	8	8	10	9	12	13	6	16	12	11	15	16
D2	90	30	60	45	60	60	45	90	30	30	60	45	60	60	45	60	10	30	30	30	45	45	45	30	30	60	60	45	45	45
D3	12	10	15	10	9	8	7	7	8	5	4	4	5	2	5	5	2	4	3	6	5	7	7	5	7	5	7	3	4	3
C1	42	40	38	35	41	35	37	39	42	36	33	36	31	33	32	32	35	28	31	30	31	31	33	34	31	37	33	30	31	31
C2	10.9	11.2	9.3	8.9	9.8	8.5	10.9	8.8	9.5	7.9	9.1	7.5	7.5	7.6	8.5	9.5	5.8	3.2	8.1	6.2	4.9	10.1	9.2	9.3	10.2	14.9	9	8.1	8.6	8
C3	2136	2240	2364	2371	2327	2414	2374	2315	2395	2458	2540	2474	2635	2600	2460	2642	2708	3243	2617	2951	2983	2779	2281	2670	2637	2518	2867	2996	2675	2801
C4	5343	5312	5218	4864	4758	4412	5225	4880	4712	4724	4644	4656	4412	4332	5124	4904	4868	4756	4612	4368	4132	5144	4904	4880	4792	4748	4332	4457	4456	4153
F	1.75	1.75	2.25	2.00	1.75	3.00	1.75	2.00	1.75	2.00	2.75	3.00	3.00	3.00	2.75	3.75	3.50	4.00	3.00	3.25	4.25	2.75	2.75	2.75	2.25	3.00	2.50	3.75	3.25	3.00
T1	45	20	30	20	30	30	30	60	20	20	45	30	45	45	15	10	5	5	10	15	20	15	10	10	15	30	30	15	10	15
T2	3	4	3	2.5	3	2	2.5	4	3	2	2	2.5	2	2	1	1	1	0.5	1	0.5	0.5	0.5	0.5	0.5	0.5	1	1	0.5	0.5	1
T3	180	180	180	180	180	90	180	90	180	180	90	29	90	90	90	90	90	60	60	60	90	90	90	90	90	90	90	60	90	90
T4	19	16	16	18	18	10	10	15	14	12	8	7	9	7	10	4	7	5	8	6	6	8	9	12	11	10	11	7	12	12
T5	60	30	90	60	60	60	45	60	30	30	60	59	60	60	20	15	20	5	15	15	15	15	20	25	20	15	20	15	25	15
A	1.80	1.80	2.80	3.20	2.00	3.80	2.00	2.40	2.20	3.20	3.80	3.60	3.80	4.20	2.20	3.00	3.20	4.60	2.80	3.60	4.20	3.40	1.80	2.60	2.00	1.60	2.20	3.60	2.60	2.20
I1	15	15	25	25	15	50	15	15	25	25	50	49	50	50	25	35	38	50	35	50	80	25	5	18	5	29	25	25	25	32
G	2.33	1.17	2.17	2.50	1.83	2.83	2.00	1.33	2.00	2.83	4.00	3.00	4.00	4.50	2.17	2.00	3.00	4.00	2.50	2.83	3.83	3.00	1.50	2.17	1.17	2.50	3.33	3.67	2.00	3.33
PT	1.83	1.00	1.67	2.33	1.17	2.33	1.00	1.50	1.50	2.00	2.83	2.67	3.17	2.83	1.33	1.33	3.17	4.00	1.83	2.67	3.17	2.17	1.00	1.33	1.00	1.33	2.17	3.00	1.67	2.67
PR1	1800	2200	2200	2100	2000	2300	1900	2000	2100	2200	2400	2600	2500	2500	3600	3200	4100	4800	4200	4300	4600	4400	3500	3900	4100	4300	4200	4500	4250	4200
ALP	1.68	1.76	2.01	2.44	1.76	2.91	1.87	1.92	2.01	2.61	3.28	2.98	3.34	3.43	2.29	2.61	3.37	4.24	2.93	3.31	3.77	2.95	2.01	2.43	2.03	2.22	2.68	3.55	2.58	2.96

Table 27 - Statistical Analysis of the model variables

		Wool Average	6 Comp. StDev	Cotton Average	8 Comp. StDev	Knitting Average	7 Comp. StDev	Clothing Average	9 Comp. StDev	TOTAL Average	30 Comp. StDev
Q1	Organisation	2.00	0.87	2.84	0.92	2.11	0.79	1.61	0.47	2.13	0.87
Q2	Material scrap	15.67	4.08	14.88	2.42	13.29	4.99	16.44	2.19	15.13	3.49
Q3	Failure costs	14.17	5.91	10.88	4.70	11.14	3.80	18.67	3.12	13.93	5.34
Q4	Quality costs	1.67	1.21	3.75	2.31	2.29	0.95	1.22	0.44	2.23	1.68
D1	Timeliness of delivery	19.17	4.17	13.13	4.32	7.29	3.30	12.22	3.31	12.70	5.35
D2	Delivery lead time	57.50	19.94	52.50	19.64	35.71	15.92	45.00	10.61	47.33	17.55
D3	Average lateness of delivery	10.67	2.50	5.25	1.98	4.29	1.38	5.33	1.73	6.13	2.96
C1	Raw material in warehouse	38.50	3.02	35.88	3.56	31.29	2.14	32.33	2.18	34.27	3.82
C2	Work-in-process	9.77	1.09	8.60	1.21	6.60	2.22	9.71	2.09	8.70	2.10
C3	Value Added/employee	2308.50	102.75	2473.92	112.16	2800.43	269.32	2691.33	207.81	2582.24	256.32
C4	Production costs/employee	4984.50	369.83	4698.13	275.72	4680.57	339.29	4651.78	319.02	4737.40	331.57
F1	Design flexibility	2.67	0.82	3.25	1.39	3.43	0.98	2.33	1.00	2.90	1.12
F2	Production flexibility	2.33	0.52	1.88	0.64	3.71	0.76	3.56	0.73	2.90	1.03
F3	Materials flexibility	1.67	0.82	2.00	0.00	3.29	0.49	2.89	0.60	2.50	0.82
F4	People flexibility	1.67	0.82	2.50	0.76	3.57	0.79	2.78	0.67	2.67	0.96
T1	Cycle time	29.17	9.17	36.88	14.13	11.43	5.56	16.67	7.91	23.33	13.85
T2	Setup time	2.92	0.66	2.44	0.73	0.79	0.27	0.67	0.25	1.62	1.10
T3	Time to introduce new products	165.00	36.74	123.75	46.58	77.14	16.04	86.67	10.00	110.00	44.10
T4	Waste time	16.17	3.25	10.25	3.11	6.57	1.99	10.22	1.86	10.57	4.04
T5	Materials residence in warehous	60.00	18.97	50.63	13.74	15.00	5.00	18.89	4.17	34.67	22.16
A1	Motivation	2.33	1.21	3.00	1.07	3.29	0.95	2.67	0.87	2.83	1.02
A2	Communication	2.83	0.75	3.00	0.76	3.57	0.53	2.56	0.53	2.97	0.72
A3	Training	2.00	1.26	3.13	1.25	3.57	1.27	2.00	1.00	2.67	1.32
A4	Working conditions	3.00	0.89	4.00	1.20	3.71	1.11	2.67	1.22	3.33	1.21
A5	Absenteeism	8.17	0.75	8.25	1.67	8.00	1.63	8.89	1.69	8.37	1.50
I1	N. of new products launched	24.17	13.57	35.00	16.48	44.71	17.90	21.00	9.81	30.90	16.75
G1	CAD/CAM	1.50	1.05	2.75	2.05	3.43	0.79	3.22	1.56	2.80	1.58
G2	Robotics/automation	2.83	0.75	3.38	0.92	3.14	0.69	2.67	1.12	3.00	0.91
G3	Materials handling	1.67	0.52	3.13	1.36	2.14	1.07	2.00	0.87	2.27	1.11
G4	Warehousing	1.83	0.41	2.88	0.99	2.29	1.11	1.78	0.83	2.20	0.96
G5	CIM/integration	1.67	0.82	2.00	0.93	2.43	0.98	2.00	1.00	2.03	0.93
G6	Equipment	3.33	0.82	3.63	0.92	4.00	0.82	3.44	0.88	3.60	0.86
PT1	Group technology	0.00	0.00	0.00	0.00	1.57	1.62	1.11	1.36	0.70	1.24
PT2	Just-in-time	0.50	0.84	0.50	0.93	1.29	2.21	0.56	0.73	0.70	1.26
PT3	MRP	1.83	0.98	2.50	1.20	2.43	1.13	1.78	0.83	2.13	1.04
PT4	Maintenance management	1.67	0.52	1.88	0.83	1.71	0.95	1.33	0.50	1.63	0.72
PT5	Work measurement (study)	1.83	0.75	2.63	1.30	3.57	1.13	2.67	1.22	2.70	1.24
PT6	Layout design	2.67	0.82	3.13	0.64	3.57	1.13	2.78	0.83	3.03	0.89
PT7	Inventory management	1.83	0.98	2.50	1.20	2.43	1.13	1.78	0.83	2.13	1.04
PR1	Output rate/employee	2100.00	178.89	2275.00	260.49	4114.29	555.06	4150.00	297.91	3231.67	1037.94
ALP		2.09	0.48	2.68	0.67	3.22	0.67	2.60	0.50	2.66	0.67

Table 28 - Variables after transformation

		Wool						Cotton								Knitting							Clothing								
		W.1	W.2	W.3	W.4	W.5	W.6	Co.1	Co.2	Co.3	Co.4	Co.5	Co.6	Co.7	Co.8	K.1	K.2	K.3	K.4	K.5	K.6	K.7	Cl.1	Cl.2	Cl.3	Cl.4	Cl.5	Cl.6	Cl.7	Cl.8	Cl.9
Q1	Quality System	1.25	1.25	1.50	2.25	2.25	3.50	1.25	2.00	2.50	2.75	3.25	3.25	3.75	4.00	1.00	1.25	2.00	2.25	2.25	2.75	3.25	1.25	1.25	1.25	1.25	1.25	1.75	2.00	2.00	2.50
Q2	Material scrap	1	3	1	2	2	3	2	3	1	2	3	3	3	2	2	1	3	4	3	3	3	2	2	2	2	2	2	3	2	3
Q3	Failure costs	1	3	2	3	3	4	3	2	2	3	5	3	4	4	2	3	3	5	3	3	3	2	2	2	1	1	2	2	2	1
D1	Timeliness of de	1	3	1	3	2	2	2	4	2	4	2	4	3	3	3	5	4	5	4	4	4	4	3	3	4	2	3	3	3	2
D2	Delivery lead tin	1	4	2	3	2	2	3	1	4	4	3	2	2	2	3	2	5	4	4	4	3	3	3	4	4	2	2	3	3	3
D3	Average lateness	1	1	1	1	2	2	2	2	2	3	3	3	3	4	3	3	4	3	4	3	3	2	2	3	2	3	2	4	3	4
C1	Raw material in	1	1	2	3	1	3	2	2	1	2	2	3	3	3	3	3	3	4	3	4	3	3	3	3	3	2	3	4	3	3
C2	Work-in-process	2	2	2	3	2	3	2	3	2	3	3	2	3	3	3	2	4	4	3	3	4	2	2	2	2	1	2	3	3	3
C3	V.A./employee	1	1	2	2	1	2	2	1	2	2	2	3	3	3	1	3	4	5	3	5	5	4	1	4	3	3	5	5	4	4
F1	Design flexibility	2	2	3	2	3	4	2	2	2	2	4	4	5	5	2	4	3	3	3	4	5	2	1	2	1	2	3	4	3	3
F2	Production flexil	2	3	2	3	2	2	1	2	2	1	3	2	2	2	3	4	4	5	3	3	4	4	4	4	4	4	2	4	3	3
F3	Materials flexibi	2	1	2	1	1	3	2	2	2	2	2	2	2	2	3	4	3	3	3	3	4	2	3	3	2	3	3	3	4	3
F4	People flexibility	1	1	2	2	1	3	2	2	1	3	3	3	3	3	3	3	4	5	3	3	4	3	3	2	2	3	2	4	3	3
T1	Cycle time	1	3	2	3	2	2	2	1	3	3	2	1	1	1	4	4	5	5	4	4	3	4	4	4	4	2	2	4	4	4
T2	Setup time	1	1	1	1	1	2	1	1	1	1	2	2	2	2	4	4	4	5	4	5	5	5	5	5	5	4	4	5	5	4
T3	Time to introduc	1	1	1	1	1	3	1	3	1	1	3	3	3	3	3	3	3	4	4	4	3	3	3	3	3	3	3	4	3	3
T4	Waste time	3	3	3	3	3	4	4	3	3	3	4	4	4	4	4	5	4	5	4	4	4	4	4	3	3	4	3	4	3	3
T5	Materials resider	2	4	1	2	2	2	3	2	4	4	2	2	2	2	4	5	4	5	5	5	5	5	4	4	4	5	4	5	4	5
A1	Motivation	1	1	3	3	2	4	2	3	1	3	4	3	4	4	2	3	3	5	3	3	4	4	2	3	2	2	2	4	3	2
A2	Communication	2	2	3	3	3	4	2	3	2	3	4	3	3	4	3	4	3	4	3	4	4	3	3	3	2	2	2	3	3	2
A3	Training	1	1	2	3	1	4	2	1	3	3	3	4	4	5	2	2	4	5	3	4	5	3	1	1	2	1	2	4	2	2
A4	Working conditi	3	2	3	4	2	4	2	3	3	4	5	5	5	5	2	3	4	5	3	4	5	4	1	3	2	1	3	4	2	4
A5	Absenteeism	2	3	3	3	2	3	2	2	2	3	3	3	3	3	2	3	2	4	2	3	3	3	2	3	2	2	2	3	3	1
I1	N. of new produ	2	2	3	3	2	5	2	2	3	3	5	5	5	5	3	4	4	5	4	5	5	3	1	2	1	3	3	3	3	4
G1	CAD/CAM	2	0	1	1	2	3	1	0	1	2	5	3	5	5	2	4	4	4	3	3	4	4	1	3	1	4	4	5	2	5
G2	Robotics/automa	3	2	3	3	2	4	3	2	3	3	4	3	4	5	3	2	3	4	3	3	4	3	2	2	1	3	5	3	2	3
G3	Materials handli	2	1	2	2	1	2	2	1	2	3	4	4	4	5	1	1	2	4	2	2	3	2	1	2	1	2	2	4	2	2
G4	Warehousing	2	1	2	2	2	2	2	2	2	3	4	2	4	4	1	1	2	3	2	3	4	2	1	2	1	2	1	3	1	3
G5	CIM/integration	1	1	2	3	1	2	1	1	1	2	3	2	3	3	2	1	3	4	2	2	3	3	1	1	1	1	3	3	2	3
G6	Equipment	4	2	3	4	3	4	3	2	3	4	4	4	4	5	4	3	4	5	3	4	5	4	3	3	2	3	5	4	3	4
PT1	Group technolog															0	0	3	4	2	0	2	2	0	0	0	0	3	3	0	2
PT2	Just-in-time	1	0	0	0	0	2	0	0	0	2	0	2	0	0	0	0	4	5	0	0	0	1	0	0	0	0	1	2	0	1
PT3	MRP	1	1	2	3	1	3	1	1	2	2	4	3	4	3	1	1	3	3	2	4	3	2	1	1	1	1	2	3	2	3
PT4	Maintenance ma	2	1	2	2	1	2	1	2	1	1	2	2	3	3	1	1	2	3	1	1	3	1	1	1	1	1	2	2	1	2
PT5	Work measurem	2	1	2	3	1	2	1	2	1	2	4	3	4	4	3	2	4	5	3	3	5	3	1	2	1	2	4	4	3	4
PT6	Layout design	4	2	2	3	3	2	2	3	3	3	3	3	4	4	2	3	3	5	3	4	5	4	2	3	2	3	2	4	2	3
PT7	Inventory manag	1	1	2	3	1	3	1	1	2	2	4	3	4	3	1	1	3	3	2	4	3	2	1	1	1	1	2	3	2	3
PR1	Output rate/empl	1	3	3	2	2	3	2	2	2	3	5	4	5	5	1	1	2	5	3	3	5	4	1	2	3	3	3	5	3	3
ALP		1.68	1.76	2.01	2.44	1.76	2.91	1.87	1.92	2.01	2.61	3.28	2.98	3.34	3.43	2.29	2.61	3.37	4.24	2.93	3.31	3.77	2.95	2.01	2.43	2.03	2.22	2.68	3.55	2.58	2.96

Table 29 - Correlation among variables

	Q1	Q2	Q3	Q4	D1	D2	D3	C1	C2	C3	C4	F1	F2	F3	F4	T1	T2	T3	T4	T5	A1	A2	A3	A4	A5	I1	G1	G2	G3	G4	G5	G6	PT1	PT2	PT3	PT4	PT5	PT6	PT7	PR1	ALP
Q1	1.00																																								
Q2	-0.53	1.00																																							
Q3	-0.61	0.63	1.00																																						
Q4	0.88	-0.50	-0.67	1.00																																					
D1	-0.01	0.35	0.17	-0.14	1.00																																				
D2	0.05	0.23	0.15	0.06	0.39	1.00																																			
D3	-0.35	0.40	0.28	-0.45	0.58	0.36	1.00																																		
C1	-0.17	0.42	0.21	-0.25	0.62	0.33	0.61	1.00																																	
C2	-0.52	0.63	0.58	-0.46	0.45	0.34	0.40	0.53	1.00																																
C3	0.21	-0.49	-0.20	0.18	-0.59	-0.38	-0.58	-0.80	-0.62	1.00																															
C4	-0.71	0.40	0.24	-0.49	0.19	0.07	0.57	0.51	0.47	-0.58	1.00																														
F1	0.76	-0.45	-0.63	0.71	-0.06	0.14	-0.38	-0.35	-0.51	0.44	-0.64	1.00																													
F2	-0.31	-0.20	0.08	-0.21	-0.53	-0.40	-0.32	-0.53	-0.21	0.55	-0.04	-0.07	1.00																												
F3	-0.05	-0.10	0.01	-0.09	-0.33	-0.13	-0.50	-0.58	-0.31	0.57	-0.43	0.28	0.47	1.00																											
F4	0.30	-0.60	-0.42	0.42	-0.55	-0.30	-0.69	-0.77	-0.63	0.73	-0.44	0.45	0.52	0.61	1.00																										
T1	0.35	0.07	-0.05	0.40	0.36	0.80	0.26	0.45	0.26	-0.44	0.01	0.22	-0.65	-0.46	-0.37	1.00																									
T2	0.09	0.12	-0.10	0.04	0.50	0.43	0.58	0.83	0.31	-0.74	0.41	-0.12	-0.67	-0.73	-0.68	0.66	1.00																								
T3	-0.19	0.39	0.14	-0.30	0.60	0.12	0.71	0.79	0.40	-0.68	0.53	-0.38	-0.57	-0.66	-0.72	0.23	0.73	1.00																							
T4	-0.27	0.40	0.46	-0.42	0.61	0.33	0.73	0.74	0.47	-0.68	0.42	-0.50	-0.46	-0.62	-0.81	0.33	0.68	0.76	1.00																						
T5	0.33	0.15	-0.20	0.35	0.63	0.56	0.52	0.54	0.16	-0.62	0.21	0.18	-0.66	-0.60	-0.44	0.74	0.73	0.50	0.51	1.00																					
A1	0.53	-0.64	-0.62	0.59	-0.34	-0.06	-0.43	-0.61	-0.64	0.59	-0.41	0.62	0.28	0.27	0.75	-0.04	-0.36	-0.54	-0.60	0.02	1.00																				
A2	0.52	-0.47	-0.72	0.55	-0.28	-0.03	-0.31	-0.42	-0.65	0.36	-0.34	0.64	0.23	0.32	0.58	-0.09	-0.26	-0.44	-0.56	0.06	0.79	1.00																			
A3	0.73	-0.63	-0.61	0.72	-0.36	-0.28	-0.46	-0.52	-0.73	0.60	-0.54	0.70	0.10	0.19	0.67	-0.07	-0.29	-0.38	-0.62	-0.06	0.72	0.61	1.00																		
A4	0.76	-0.56	-0.59	0.78	-0.24	-0.05	-0.34	-0.35	-0.69	0.48	-0.47	0.71	-0.03	0.00	0.48	0.17	-0.07	-0.26	-0.40	0.17	0.72	0.57	0.82	1.00																	
A5	-0.33	0.47	0.55	-0.42	0.17	0.16	0.08	0.33	0.37	-0.31	0.02	-0.41	-0.22	-0.01	-0.46	0.11	0.18	0.10	0.37	-0.06	-0.68	-0.60	-0.58	-0.47	1.00																
I1	0.75	-0.60	-0.65	0.71	-0.21	-0.06	-0.42	-0.41	-0.62	0.52	-0.61	0.84	0.11	0.36	0.61	0.06	-0.24	-0.42	-0.60	-0.01	0.65	0.67	0.81	0.77	-0.45	1.00															
G1	0.45	-0.32	-0.24	0.52	-0.29	-0.01	-0.65	-0.58	-0.33	0.66	-0.60	0.68	0.26	0.42	0.64	-0.04	-0.54	-0.61	-0.64	-0.26	0.53	0.33	0.58	0.59	-0.27	0.63	1.00														
G2	0.60	-0.36	-0.46	0.61	0.04	0.16	-0.22	-0.22	-0.37	0.34	-0.46	0.61	-0.26	0.09	0.36	0.31	-0.05	-0.18	-0.32	0.15	0.41	0.26	0.66	0.63	-0.25	0.66	0.60	1.00													
G3	0.71	-0.47	-0.53	0.80	-0.08	-0.01	-0.45	-0.33	-0.45	0.42	-0.46	0.66	-0.07	0.00	0.51	0.24	-0.12	-0.26	-0.43	0.17	0.65	0.40	0.74	0.78	-0.56	0.63	0.64	0.68	1.00												
G4	0.75	-0.48	-0.39	0.74	-0.12	0.06	-0.35	-0.25	-0.46	0.37	-0.51	0.66	-0.15	-0.04	0.41	0.34	-0.02	-0.17	-0.31	0.18	0.53	0.36	0.71	0.77	-0.41	0.69	0.59	0.59	0.79	1.00											
G5	0.50	-0.59	-0.42	0.53	-0.32	-0.17	-0.40	-0.62	-0.66	0.67	-0.49	0.53	0.18	0.16	0.67	-0.10	-0.36	-0.40	-0.42	-0.11	0.66	0.36	0.77	0.76	-0.38	0.61	0.66	0.69	0.66	0.57	1.00										
G6	0.52	-0.37	-0.41	0.52	-0.10	0.00	-0.33	-0.42	-0.58	0.54	-0.48	0.57	0.03	0.25	0.55	0.00	-0.35	-0.27	-0.41	-0.08	0.51	0.43	0.70	0.70	-0.37	0.67	0.68	0.84	0.66	0.56	0.80	1.00									
PT1	0.00	-0.49	-0.09	-0.01	-0.45	-0.32	-0.39	-0.48	-0.52	0.74	-0.29	0.18	0.46	0.36	0.58	-0.40	-0.47	-0.44	-0.41	-0.53	0.37	0.07	0.42	0.35	-0.05	0.26	0.50	0.37	0.26	0.17	0.67	0.50	1.00								
PT2	0.13	-0.53	-0.33	0.21	-0.28	-0.32	-0.29	-0.20	-0.54	0.43	-0.06	0.10	0.29	0.15	0.57	-0.30	-0.22	-0.22	-0.32	-0.23	0.44	0.25	0.43	0.43	-0.32	0.24	0.31	0.27	0.35	0.14	0.51	0.46	0.67	1.00							
PT3	0.79	-0.56	-0.52	0.75	-0.18	-0.17	-0.36	-0.46	-0.63	0.51	-0.63	0.72	-0.02	0.08	0.53	0.06	-0.19	-0.35	-0.42	0.11	0.61	0.47	0.83	0.84	-0.39	0.76	0.60	0.62	0.71	0.73	0.78	0.64	0.30	0.32	1.00						
PT4	0.62	-0.52	-0.46	0.65	-0.04	0.28	-0.15	-0.23	-0.57	0.35	-0.42	0.64	0.00	0.03	0.42	0.39	0.06	-0.22	-0.20	0.31	0.57	0.38	0.63	0.74	-0.35	0.64	0.48	0.69	0.69	0.66	0.69	0.65	0.38	0.37	0.62	1.00					
PT5	0.49	-0.56	-0.38	0.53	-0.38	-0.07	-0.55	-0.65	-0.68	0.74	-0.58	0.65	0.27	0.39	0.73	-0.05	-0.44	-0.57	-0.52	-0.21	0.64	0.42	0.72	0.74	-0.29	0.73	0.76	0.67	0.66	0.60	0.91	0.80	0.66	0.43	0.73	0.73	1.00				
PT6	0.41	-0.46	-0.24	0.39	-0.35	0.03	-0.30	-0.30	-0.51	0.55	-0.31	0.49	0.31	0.12	0.46	0.05	-0.21	-0.28	-0.36	-0.17	0.54	0.43	0.60	0.66	-0.48	0.59	0.54	0.38	0.58	0.72	0.50	0.56	0.42	0.32	0.48	0.56	0.61	1.00			
PT7	0.79	-0.56	-0.52	0.75	-0.18	-0.17	-0.36	-0.46	-0.63	0.51	-0.63	0.72	-0.02	0.08	0.53	0.06	-0.19	-0.35	-0.42	0.11	0.61	0.47	0.83	0.84	-0.39	0.76	0.60	0.62	0.71	0.73	0.78	0.64	0.30	0.32	1.00	0.62	0.73	0.48	1.00		
PR1	-0.17	-0.25	0.16	-0.16	-0.54	-0.44	-0.54	-0.76	-0.31	0.82	-0.39	0.07	0.77	0.70	0.64	-0.64	-0.89	-0.74	-0.59	-0.82	0.30	0.13	0.23	0.03	-0.05	0.22	0.48	0.03	0.04	-0.02	0.39	0.26	0.66	0.27	0.15	-0.01	0.50	0.27	0.15	1.00	
ALP	0.60	-0.70	-0.55	0.64	-0.51	-0.29	-0.66	-0.73	-0.76	0.82	-0.63	0.70	0.37	0.43	0.85	-0.21	-0.54	-0.66	-0.75	-0.30	0.80	0.62	0.88	0.79	-0.52	0.81	0.78	0.60	0.73	0.66	0.84	0.73	0.62	0.53	0.80	0.62	0.88	0.66	0.80	0.54	1.00

5.3.2. ALP evaluation and analysis

The analysis of so many variables can be very complex. Table 30 shows how different variables can present a very different picture. Whilst a few companies have consistently high rankings and a few have consistently low rankings, the majority exhibit considerable variation depending on the variable chosen. This situation shows that there are companies in this sample with different business strategies. While some compete on quality, others compete on delivery service and others on price. For instance, in the small sample of variables presented in Table 30, company K.4 always has high rankings and it seems to compete on quality. However, company K.7 also has a high ALP ranking (2nd place), but in material scrap it is in a middle position (11th). This company seems to compete on flexibility. Another company (W.2), which has a very low ALP ranking (28th), unexpectedly presents a very high ranking in material scrap (2nd position). This company seems to compete on quality. In this case, one can ask: How can a low ALP company have such a high quality performance? This situation can have the following interpretation: the company produces very low price products (which means low "quality" products). It means that, regarding the company standards, most of the items manufactured have enough quality. Therefore, there is a small level of material scrap.

To know which companies are performing better in the context of Lean Manufacturing we proposed in a first approach the evaluation of the Average Level of Performance (ALP). ALP gives a rapid picture of the situation. From the comparison between ALP and the other variables (Figures 50, 51 and 52) it is possible to identify a similar pattern of evolution that results from a high correlation. Almost all the companies audited, have a quality assurance distribution performance under the ALP distribution (Figure 50).

The ranking by ALP in Table 30 shows that the best performing companies belong to the knitting, cotton and clothing sub-sectors. The results are slightly different from a simple statistical analysis as presented in Table 27. In fact the statistical analysis revealed large standard deviation values for some variables. On the opposite side most companies from the wool sub-sector present a low ALP value.

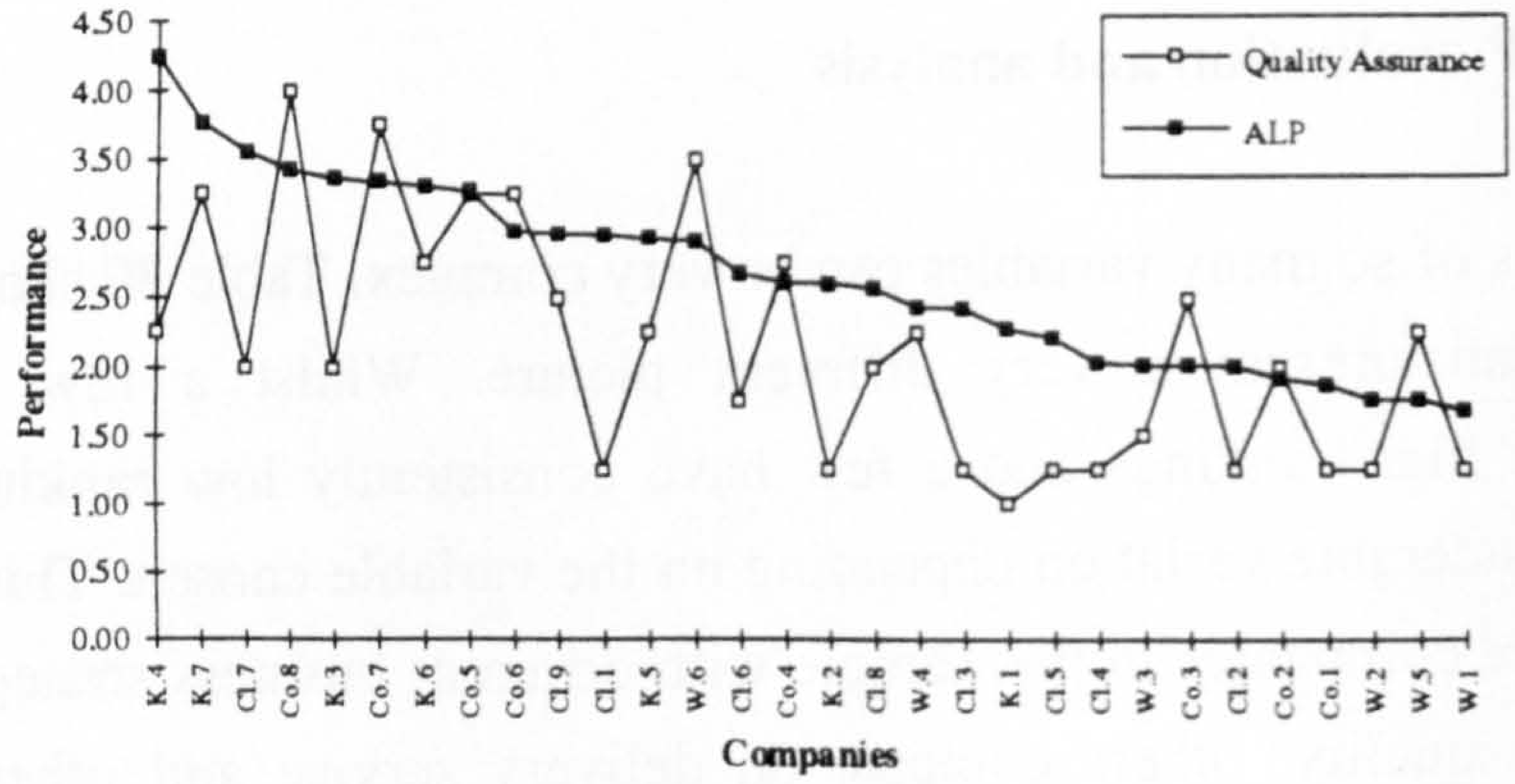

Figure 50 - Quality assurance vs. ALP evolution

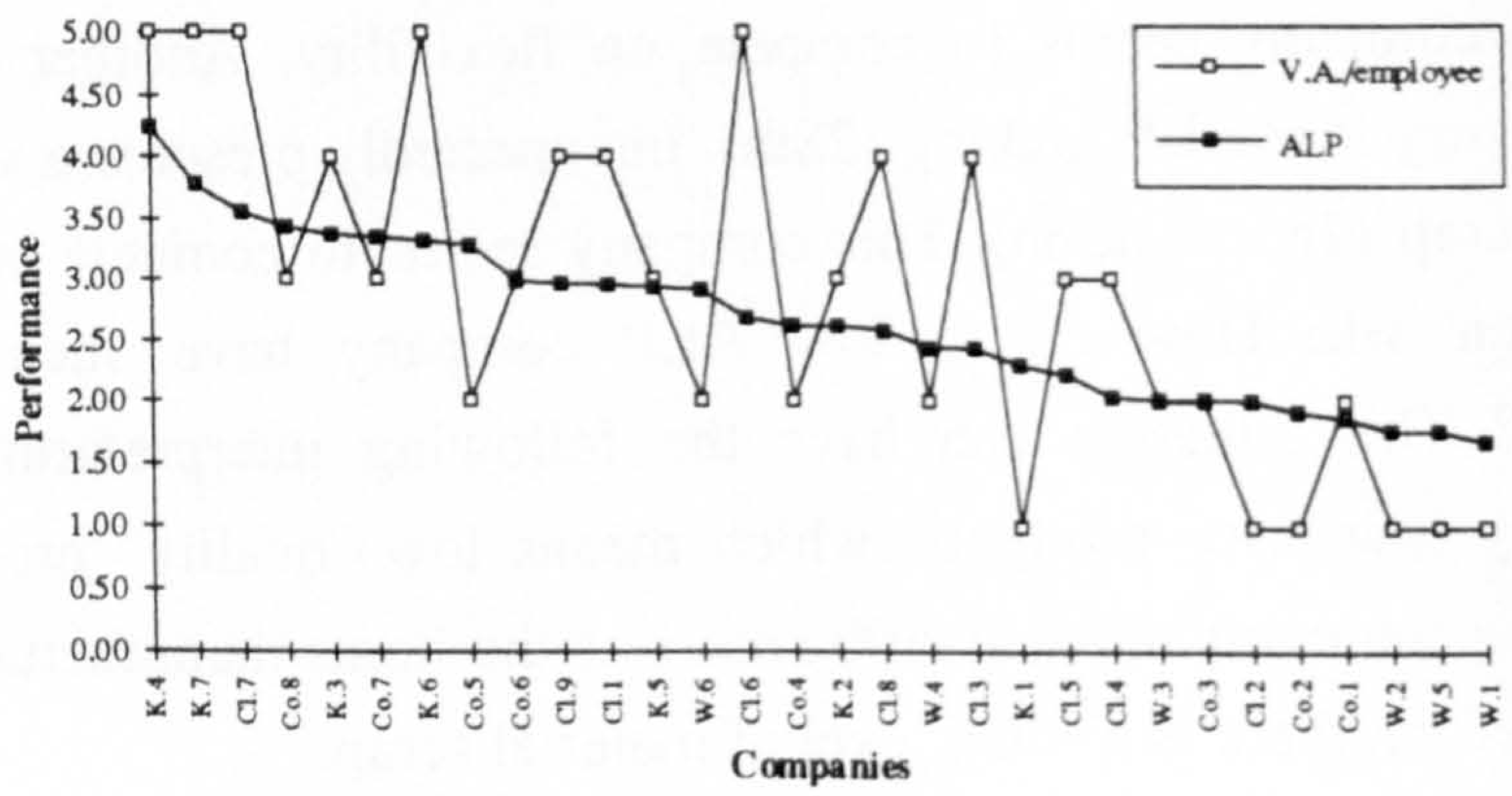

Figure 51 - Value added per employee vs. ALP evolution

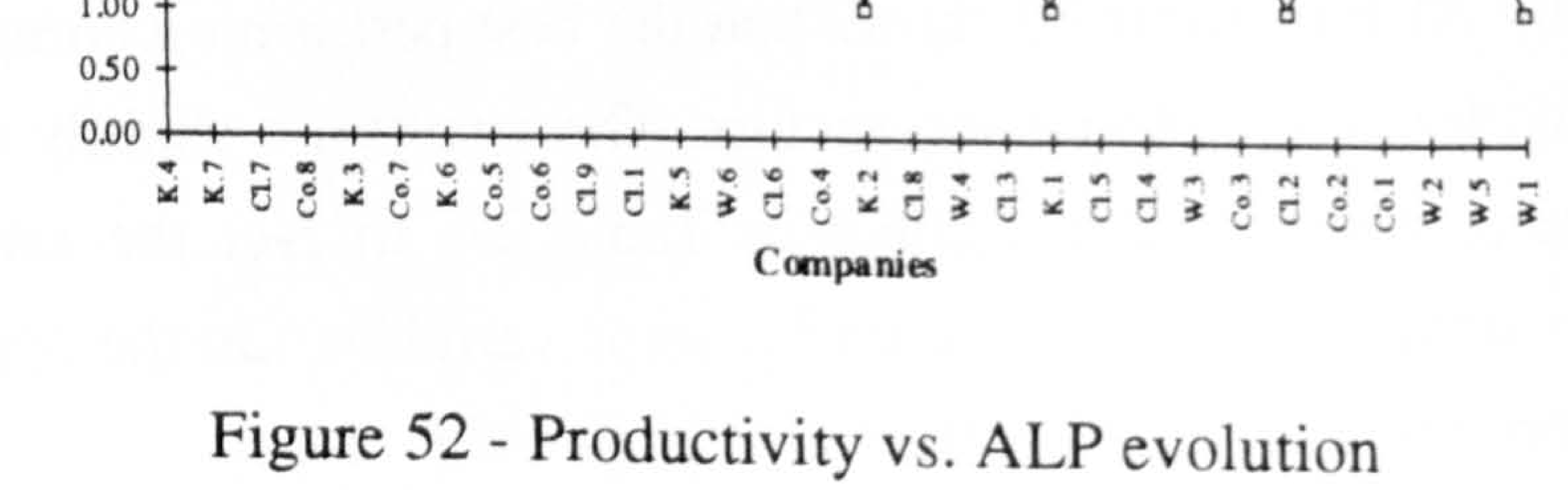

Figure 52 - Productivity vs. ALP evolution

Table 30 - Ranking by variables

	ALP	Rank	Q1 Quality Assurance	Rank	Q2 Material scrap	Rank	C3 V.A./ Emp.	Rank	PR1 Output rate/empl.	Rank
K.4	4.24	1	2.25	13	4	1	5	1	5	4
K.7	3.77	2	3.25	6	3	11	5	3	5	5
Cl.7	3.55	3	2.00	17	3	12	5	5	5	6
Co.8	3.43	4	4.00	1	2	18	3	13	5	3
K.3	3.37	5	2.00	16	3	8	4	6	2	25
Co.7	3.34	6	3.75	2	3	7	3	12	5	2
K.6	3.31	7	2.75	8	3	10	5	2	3	14
Co.5	3.28	8	3.25	4	3	5	2	24	5	1
Co.6	2.98	9	3.25	5	3	6	3	11	4	7
Cl.9	2.96	10	2.50	10	3	13	4	10	3	19
Cl.1	2.95	11	1.25	25	2	20	4	7	4	8
K.5	2.93	12	2.25	14	3	9	3	15	3	13
W.6	2.91	13	3.50	3	3	3	2	20	3	11
Cl.6	2.68	14	1.75	19	2	25	5	4	3	17
Co.4	2.61	15	2.75	7	2	17	2	23	3	12
K.2	2.61	16	1.25	24	1	30	3	14	1	29
Cl.8	2.58	17	2.00	18	2	26	4	9	3	18
W.4	2.44	18	2.25	11	2	14	2	19	2	20
Cl.3	2.43	19	1.25	27	2	22	4	8	2	26
K.1	2.29	20	1.00	30	2	19	1	29	1	28
Cl.5	2.22	21	1.25	29	2	24	3	17	3	16
Cl.4	2.03	22	1.25	28	2	23	3	16	3	15
W.3	2.01	23	1.50	20	1	28	2	18	3	10
Co.3	2.01	24	2.50	9	1	29	2	22	2	24
Cl.2	2.01	25	1.25	26	2	21	1	30	1	30
Co.2	1.92	26	2.00	15	3	4	1	28	2	23
Co.1	1.87	27	1.25	23	2	16	2	21	2	22
W.2	1.76	28	1.25	22	3	2	1	26	3	9
W.5	1.76	29	2.25	12	2	15	1	27	2	21
W.1	1.68	30	1.25	21	1	27	1	25	1	27

Another problem concerned with the ALP evaluation is that different variables can have different importance for each company. To overcome this situation the model variables were weighted and a new ALP was evaluated (the allocation of weights to the model variables was described in section 4.2.2. Table 31 shows the ALP values after weighting the model variables (column ALP-W). As we can see, the comparison between both ways of evaluating ALP do not show significant different results. The relative position of companies in the ranking remains the same. There are only two exceptions: companies Co.1 and Co.3 shifted their relative position with companies Cl.9 and W.3, respectively. Figure 53 plots the companies by decreasing value of ALP.

Table 31 - Ranking by ALP using weighted variables

	ALP	Rank	ALP-W	Rank		ALP	Rank	ALP-W	Rank
K.4	4.24	1	3.78	1	K.2	2.61	16	2.30	16
K.7	3.77	2	3.34	2	Cl.8	2.58	17	2.29	17
Cl.7	3.55	3	3.15	3	W.4	2.44	18	2.18	18
Co.8	3.43	4	3.04	4	Cl.3	2.43	19	2.15	19
K.3	3.37	5	2.99	5	K.1	2.29	20	2.03	20
Co.7	3.34	6	2.97	6	Cl.5	2.22	21	1.96	21
K.6	3.31	7	2.94	7	Cl.4	2.03	22	1.81	22
Co.5	3.28	8	2.91	8	**Co.3**	2.01	24	1.80	23
Co.6	2.98	9	2.66	9	**W.3**	2.01	23	1.79	24
Cl.1	2.95	11	2.62	10	Cl.2	2.01	25	1.78	25
Cl.9	2.96	10	2.61	11	Co.2	1.92	26	1.72	26
K.5	2.93	12	2.60	12	Co.1	1.87	27	1.68	27
W.6	2.91	13	2.58	13	W.2	1.76	28	1.59	28
Cl.6	2.68	14	2.37	14	W.5	1.76	29	1.57	29
Co.4	2.61	15	2.34	15	W.1	1.68	30	1.49	30

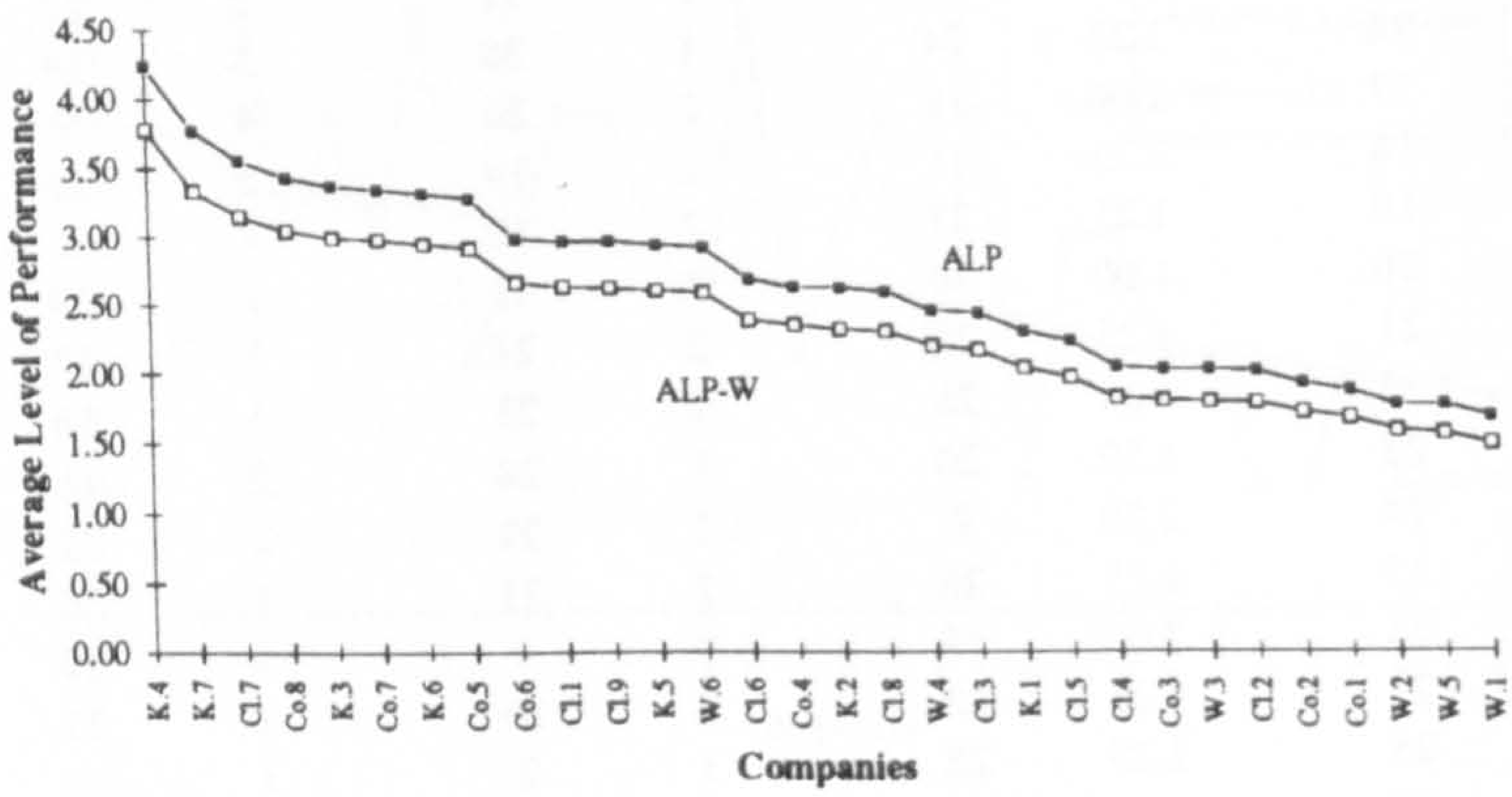

Figure 53 - ALP vs. ALP-W evolution

Using weighted variables or not, ALP seems to be a good measure of company performance. However, it does not take into account the possible interdependencies between variables. In addition, as we are using a quality strategy in modelling for Lean Manufacturing, a further analysis is presented in next sections.

5.3.3. The quality approach

In previous chapters the quality approach in modelling for Lean Manufacturing was extensively justified. The author is convinced that all action and decisions in a company derive to a large extent from the embedded total quality culture. The quality environment should be extended to all areas of the lean company. If we look at Figure 54, we can see that for the sample of companies audited there is a high correlation

(>0.6) between the Quality Assurance System and the ALP. If we consider the sub-sectors separated the correlation is even higher. In addition, we found important correlation between Q1 and most model variables (as it was shown in last section).

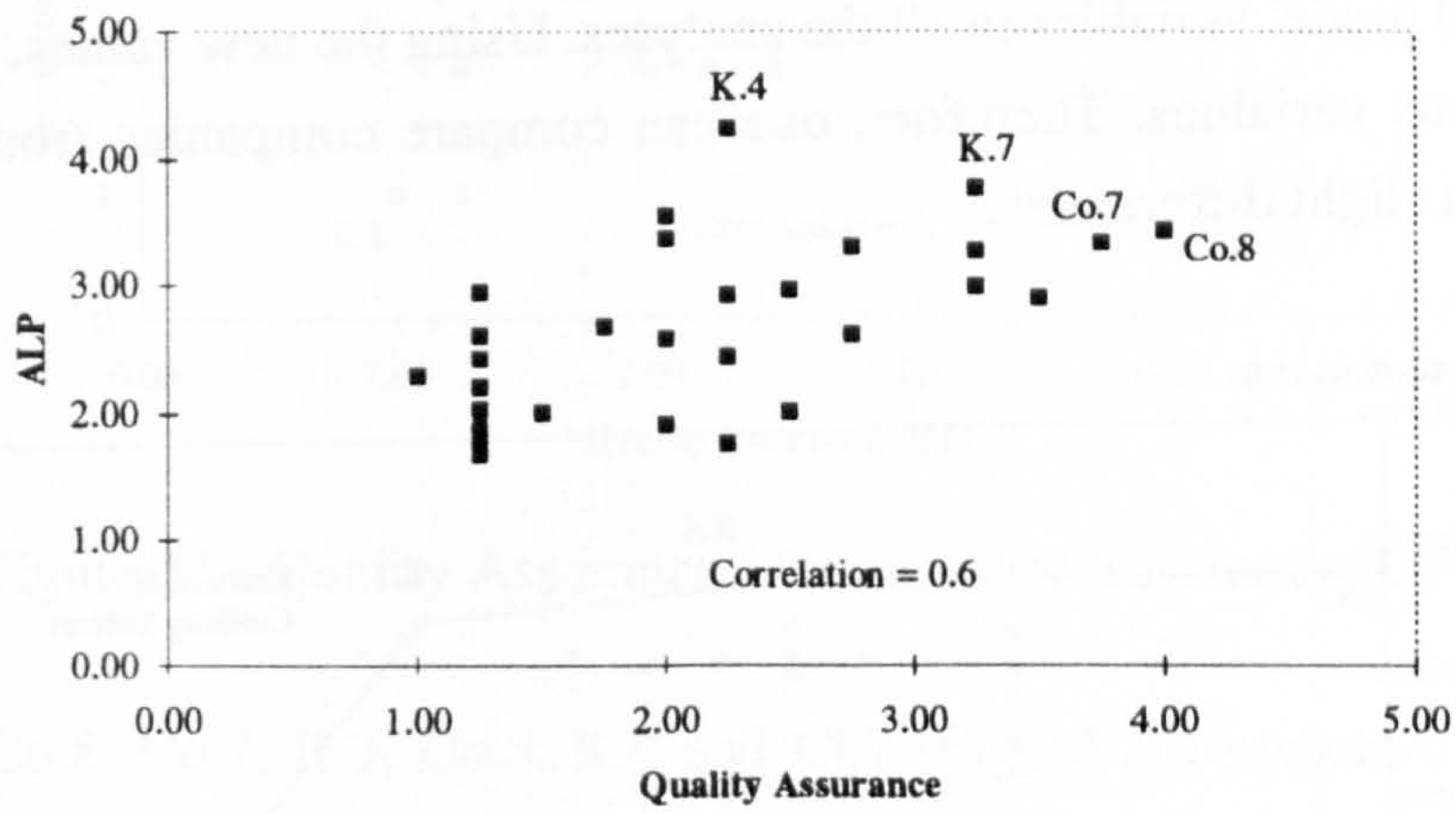

Figure 54 - Quality Assurance System / ALP correlation

This idea supports the approach adopted which is to establish relationships between the Quality Assurance System and all the other model variables. Some of these relationships are presented in the following pages.

Table 32 - Quality Assurance / Productivity Efficiency (QPE)

	Q1	PR1	Efficiency		Q1	PR1	Efficiency
W.1	1.25	1800	0.39	Cl.4	1.25	4100	0.85
Co.1	1.25	1900	0.41	K.3	2.00	4100	0.86
W.2	1.25	2200	0.47	Cl.6	1.75	4200	0.88
W.3	1.50	2200	0.48	W.6	3.50	2300	0.88
Co.2	2.00	2000	0.55	Cl.8	2.00	4250	0.89
W.5	2.25	2000	0.61	K.5	2.25	4200	0.89
W.4	2.25	2100	0.61	Cl.9	2.50	4200	0.90
Co.3	2.50	2100	0.66	Cl.5	1.25	4300	0.90
K.2	1.25	3200	0.67	Cl.1	1.25	4400	0.92
Co.4	2.75	2200	0.72	K.6	2.75	4300	0.92
Cl.2	1.25	3500	0.73	Cl.7	2.00	4500	0.94
K.1	1.00	3600	0.75	Co.7	3.75	2500	0.95
Cl.3	1.25	3900	0.81	Co.8	4.00	2500	1.00
Co.5	3.25	2400	0.84	K.4	2.25	4800	1.00
Co.6	3.25	2600	0.85	K.7	3.25	4600	1.00

Table 32 and Figure 55 present the relationship between Quality Assurance System and Productivity Efficiency (QPE). Companies in Table 32 are ranked by increasing QPE. QPE is evaluated using the Data Envelopment Analysis (DEA) principles (see section 4.2.3). Companies K.4, K.7 and Co.8 that are in the border line A-K.4-K.7-

Co.8-B have an efficiency QPE value of 1. The remaining companies have a fraction of this value, according to the distance that they are to the border. Figure 55 shows two groups of companies. This is happening because different units were used to measure productivity in different sub-sectors. To overcome this situation I used the transformed model variables in all the analyses. Using the new values, we always have homogeneous variables. Therefore, one can compare companies from different sub-sectors with slight differences.

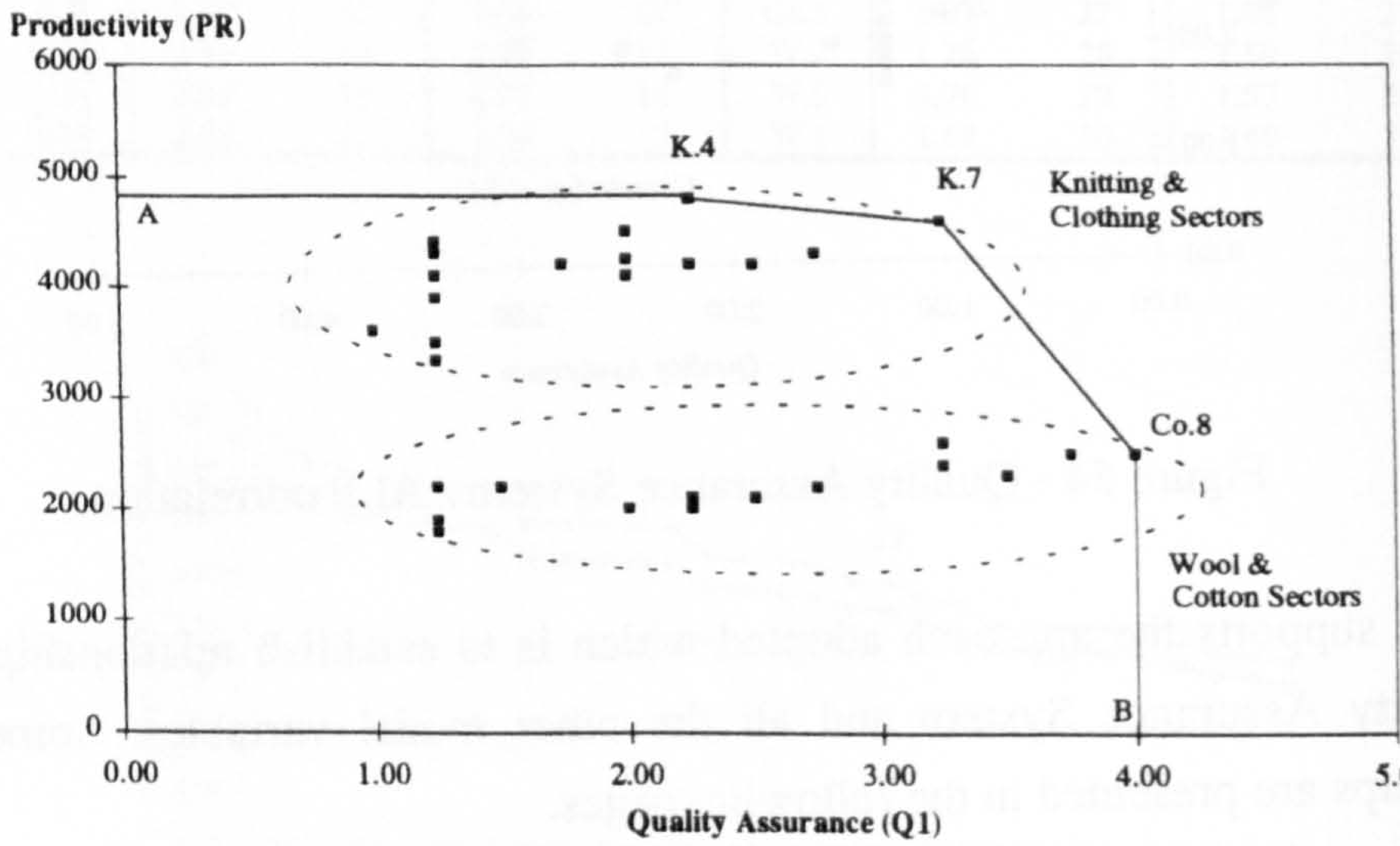

Figure 55 - Quality Assurance / Productivity efficiency (QPE)

Tables 33, 34, 35 and Figures 56, 57, 58, present some examples of the interrelationships established between Quality Assurance System and other model variables (after model variables transformation).

Table 33 - Quality Assurance / Productivity Efficiency (QPE)
(after model variables transformation)

	Q1	PR1	QPE		Q1	PR1	QPE
K.1	1.00	1	0.20	Cl.6	1.75	3	0.60
W.1	1.25	1	0.25	Cl.8	2.00	3	0.60
K.2	1.25	1	0.25	K.5	2.25	3	0.60
Cl.2	1.25	1	0.25	Cl.9	2.50	3	0.60
Co.1	1.25	2	0.40	Co.4	2.75	3	0.60
Cl.3	1.25	2	0.40	K.6	2.75	3	0.60
Co.2	2.00	2	0.40	W.6	3.50	3	0.70
K.3	2.00	2	0.40	Cl.1	1.25	4	0.80
W.4	2.25	2	0.45	Co.6	3.25	4	0.80
W.5	2.25	2	0.45	Cl.7	2.00	5	1.00
Co.3	2.50	2	0.50	K.4	2.25	5	1.00
W.2	1.25	3	0.60	Co.5	3.25	5	1.00
Cl.4	1.25	3	0.60	K.7	3.25	5	1.00
Cl.5	1.25	3	0.60	Co.7	3.75	5	1.00
W.3	1.50	3	0.60	Co.8	4.00	5	1.00

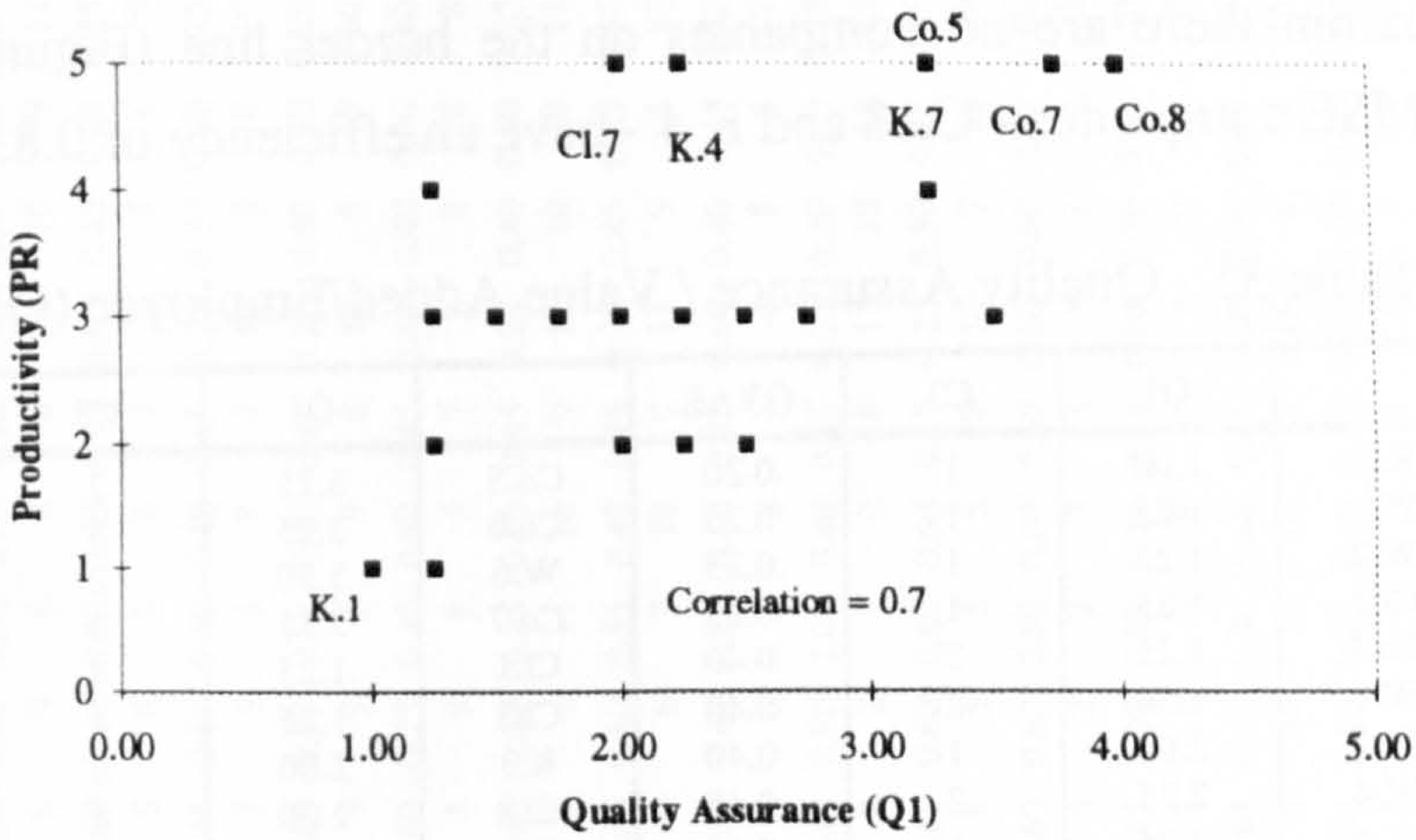

Figure 56 - Quality Assurance / Productivity Efficiency (QPE)

Companies Co.8, Co.7, K.7, Co.5, K.4 and Cl.7 (Figure 56) present the best quality assurance / productivity efficiency (QPE). As they are on the border line, they have the maximum efficiency (100%).

Table 34 - Quality Assurance / Material Scrap Efficiency (QMSE)

	Q1	Q2	**QMSE**		Q1	Q2	**QMSE**
W.1	1.25	1	0.25	Co.4	2.75	2	0.55
K.2	1.25	1	0.25	W.2	1.25	3	0.60
W.3	1.50	1	0.30	Co.2	2.00	3	0.60
K.1	1.00	2	0.40	K.3	2.00	3	0.60
Co.1	1.25	2	0.40	Cl.7	2.00	3	0.60
Cl.1	1.25	2	0.40	K.5	2.25	3	0.60
Cl.2	1.25	2	0.40	Cl.9	2.50	3	0.60
Cl.3	1.25	2	0.40	K.6	2.75	3	0.60
Cl.4	1.25	2	0.40	Co.5	3.25	3	0.65
Cl.5	1.25	2	0.40	Co.6	3.25	3	0.65
Cl.6	1.75	2	0.40	K.7	3.25	3	0.65
Cl.8	2.00	2	0.40	W.6	3.50	3	0.70
W.4	2.25	2	0.45	Co.7	3.75	3	0.75
W.5	2.25	2	0.45	K.4	2.25	4	0.80
Co.3	2.50	1	0.50	Co.8	4.00	2	0.80

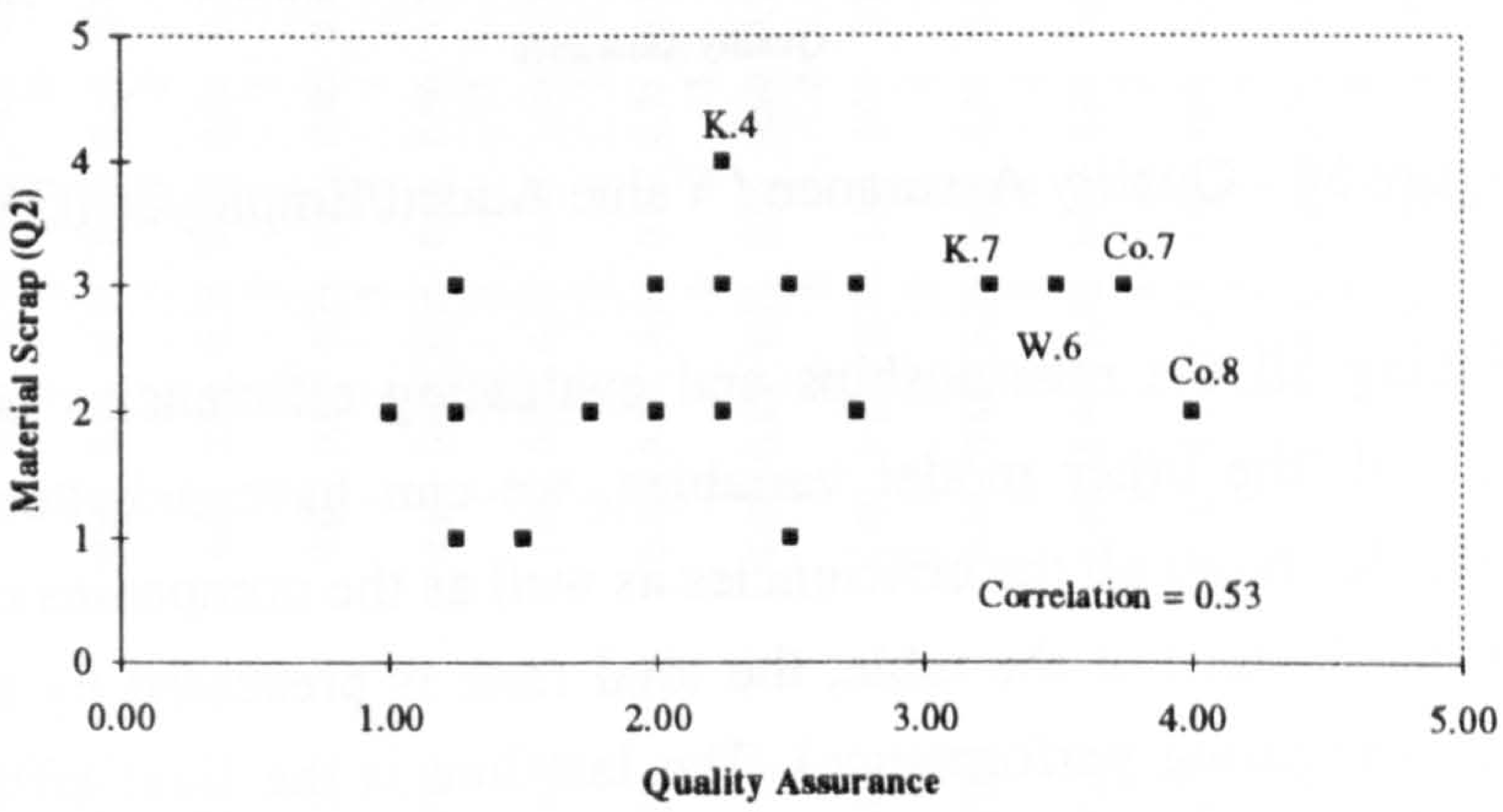

Figure 57 - Quality Assurance / Material Scrap Efficiency (QMSE)

In this situation there are no companies on the border line (Figure 57). The most efficient QMSE companies - Co.8 and K.4 - have an efficiency of 0.8.

Table 35 - Quality Assurance / Value Added/Employee (QVAE)

	Q1	C3	QVAE		Q1	C3	QVAE
K.1	1.00	1	0.20	Co.5	3.25	2	0.65
W.1	1.25	1	0.25	Co.6	3.25	3	0.65
W.2	1.25	1	0.25	W.6	3.50	2	0.70
Cl.2	1.25	1	0.25	Co.7	3.75	3	0.75
Co.1	1.25	2	0.40	Cl.1	1.25	4	0.80
W.3	1.50	2	0.40	Cl.3	1.25	4	0.80
Co.2	2.00	1	0.40	K.3	2.00	4	0.80
W.4	2.25	2	0.45	Cl.8	2.00	4	0.80
W.5	2.25	1	0.45	Cl.9	2.50	4	0.80
Co.3	2.50	2	0.50	Co.8	4.00	3	0.80
Co.4	2.75	2	0.55	Cl.6	1.75	5	1.00
K.2	1.25	3	0.60	Cl.7	2.00	5	1.00
Cl.4	1.25	3	0.60	K.4	2.25	5	1.00
Cl.5	1.25	3	0.60	K.6	2.75	5	1.00
K.5	2.25	3	0.60	K.7	3.25	5	1.00

In what concerns quality assurance / value added per employee efficiency (QVAE), companies K.7, K.6, K.4, Cl.7 and Cl.6 present the best QVAE (100%), and company K.1 is the one with worst efficiency (20%), Figure 58.

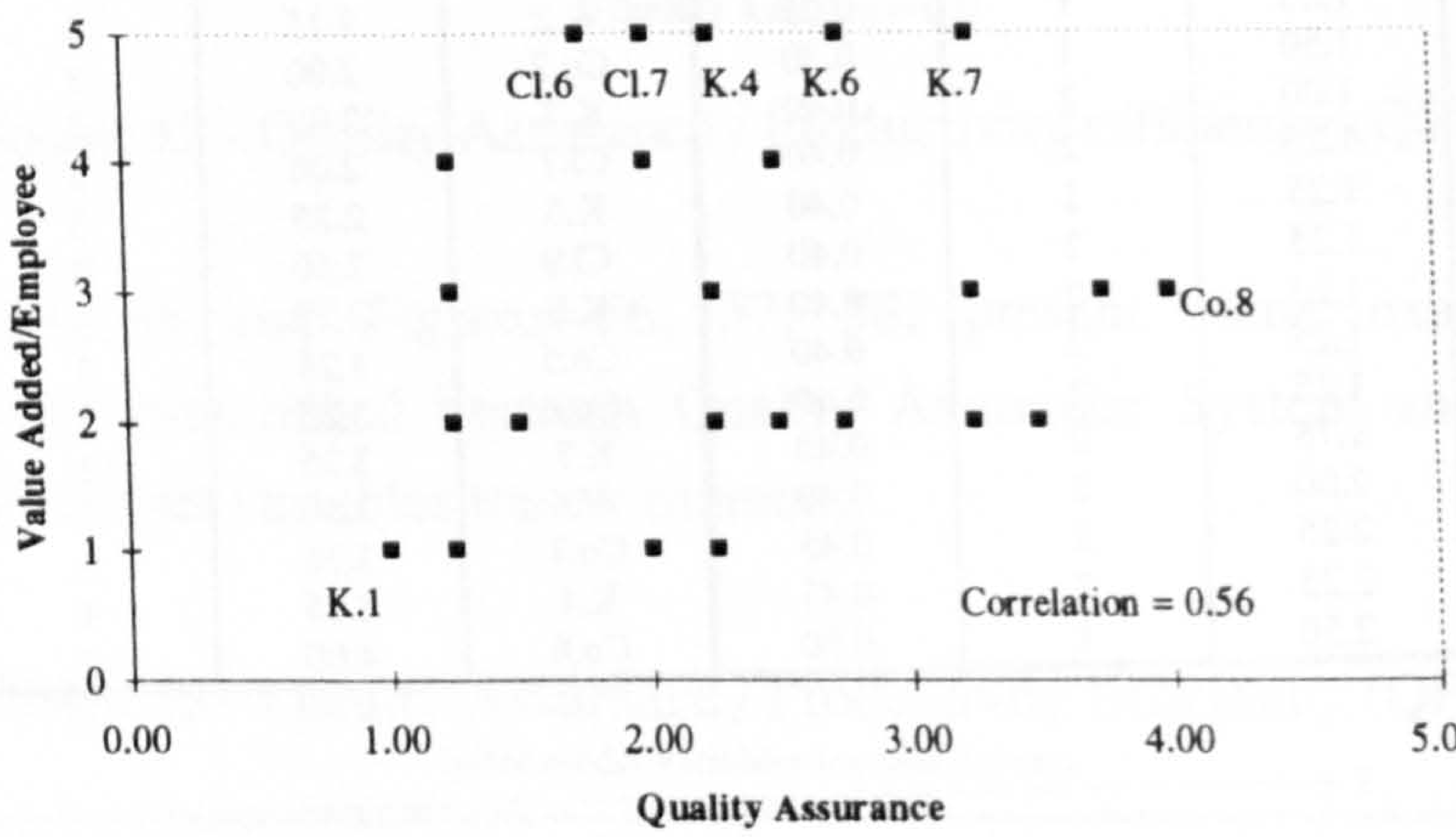

Figure 58 - Quality Assurance / Value Added/Employee (QVAE)

After establishing all the relationships and evaluating efficiencies between Quality Assurance and all the other model variables, we can have a better picture of the situation. Table 36 shows all the efficiencies as well as the companies ranking for each efficiency. In the bottom of the table, the total rank is presented by ascending order (which means decreasing performance). The last line is the final efficiency for each company. The final efficiency is calculated as the average of all the other efficiencies.

Table 36 - Final Ranking

	K.4	Co.8	Co.7	K.7	Cl.7	W.6	K.6	K.3	Co.5	Co.6	Cl.9	K.5	Cl.1	Co.4	Cl.8	K.2	Cl.3	Cl.6	Co.3	Cl.4	K.1	W.4	Cl.5	Cl.2	Co.2	W.5	W.2	W.3	Co.1	W.1
QMSE	0.80	0.80	0.75	0.65	0.60	0.70	0.60	0.60	0.65	0.65	0.60	0.60	0.40	0.55	0.40	0.25	0.40	0.40	0.50	0.40	0.40	0.45	0.40	0.40	0.60	0.45	0.60	0.30	0.40	0.25
	1	1	2	4	5	3	5	5	4	4	5	5	9	6	9	11	9	9	7	9	9	8	9	9	5	8	5	10	9	11
QFCE	0.80	0.80	0.80	0.65	0.40	0.70	0.55	0.60	0.65	1.00	1.00	0.45	0.40	0.60	0.40	0.40	0.40	0.60	0.60	0.60	0.60	0.60	0.40	0.60	0.40	0.45	0.40	0.30	0.25	0.25
	2	2	2	4	8	3	6	5	4	1	1	7	8	5	8	8	8	5	5	5	5	5	8	5	8	7	8	9	10	10
QTDE	1.00	0.80	0.75	0.80	0.60	0.70	0.80	0.80	0.65	0.80	0.50	0.80	0.80	0.80	0.60	1.00	0.60	0.60	0.50	0.80	0.60	0.60	0.40	0.60	0.80	0.45	0.60	0.30	0.40	0.25
	1	2	3	2	6	4	2	2	5	2	7	2	2	2	6	1	6	6	7	2	6	6	9	6	2	8	6	10	9	11
QDLTE	0.80	0.80	0.75	0.65	0.60	0.70	0.80	1.00	0.65	0.65	0.60	0.80	0.60	0.80	0.60	0.40	0.80	0.40	0.80	0.80	0.60	0.60	0.40	0.60	0.40	0.45	0.80	0.40	0.60	0.25
	2	2	3	5	6	4	2	1	5	5	6	2	6	2	6	8	2	8	2	2	6	6	8	6	8	7	2	8	6	9
QLD	0.60	0.80	0.75	0.65	0.80	0.70	0.60	0.80	0.65	0.65	0.80	0.80	0.40	0.60	0.60	0.60	0.60	0.40	0.50	0.40	0.60	0.45	0.60	0.40	0.40	0.45	0.25	0.30	0.40	0.25
	5	1	2	4	1	3	5	1	4	4	1	1	8	5	5	5	5	8	6	8	5	7	5	8	8	7	10	9	8	10
QRME	0.80	0.80	0.75	0.65	0.80	0.70	0.80	0.60	0.65	0.65	0.60	0.60	0.60	0.55	0.60	0.60	0.60	0.60	0.50	0.60	0.60	0.60	0.40	0.60	0.40	0.45	0.25	0.40	0.40	0.25
	1	1	2	4	1	3	1	5	4	4	5	5	5	6	5	5	5	5	7	5	5	5	9	5	9	8	10	9	9	10
QWIP	0.80	0.80	0.75	0.80	0.60	0.70	0.60	0.80	0.65	0.65	0.60	0.60	0.40	0.60	0.60	0.40	0.40	0.40	0.50	0.40	0.60	0.60	0.25	0.40	0.60	0.45	0.40	0.40	0.40	0.40
	1	1	2	1	5	3	5	1	4	4	5	5	8	5	5	8	8	8	6	8	5	5	9	8	5	7	8	8	8	8
QVAE	1.00	0.80	0.75	1.00	1.00	0.70	1.00	0.80	0.65	0.65	0.80	0.60	0.80	0.55	0.80	0.60	0.80	1.00	0.50	0.60	0.20	0.45	0.60	0.25	0.40	0.45	0.25	0.40	0.40	0.25
	1	2	3	1	1	4	1	2	5	5	2	6	2	7	2	6	2	1	8	6	12	9	6	11	10	9	11	10	10	11
QFE	0.80	0.80	0.75	0.85	0.75	0.70	0.65	0.70	0.65	0.65	0.60	0.60	0.55	0.55	0.65	0.75	0.55	0.50	0.50	0.45	0.55	0.45	0.60	0.55	0.40	0.45	0.35	0.45	0.35	0.35
	2	2	3	1	3	4	5	4	5	5	6	6	7	7	5	3	7	8	8	9	7	9	6	7	10	9	11	9	11	11
QCTE	1.00	0.80	0.75	0.65	0.80	0.70	0.80	1.00	0.65	0.65	0.80	0.80	0.80	0.60	0.80	0.80	0.80	0.40	0.60	0.80	0.80	0.60	0.40	0.80	0.40	0.45	0.60	0.40	0.40	0.25
	1	2	3	5	2	4	2	1	5	5	2	2	2	6	2	2	2	8	6	2	2	6	8	2	8	7	6	8	8	9
QSTE	1.00	0.80	0.75	1.00	1.00	0.70	1.00	0.80	0.65	0.65	0.80	0.80	1.00	0.55	1.00	0.80	1.00	0.80	0.50	1.00	0.80	0.45	0.80	1.00	0.40	0.45	0.25	0.30	0.25	0.25
	1	2	3	1	1	4	1	2	5	5	2	2	1	6	1	2	1	2	7	1	2	8	2	1	9	8	11	10	11	11
QTIE	0.80	0.80	0.75	0.65	0.80	0.70	0.80	0.60	0.65	0.65	0.60	0.80	0.60	0.55	0.60	0.60	0.60	0.60	0.50	0.60	0.60	0.45	0.60	0.60	0.60	0.45	0.25	0.30	0.25	0.25
	1	1	2	4	1	3	1	5	4	4	5	1	5	6	5	5	5	5	7	5	5	8	5	5	5	8	10	9	10	10
QWTE	1.00	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.60	0.80	0.80	0.60	0.60	1.00	0.60	0.60	0.60	0.60	0.80	0.60	0.80	0.80	0.60	0.60	0.60	0.60	0.80	0.60
	1	2	2	2	2	2	2	2	2	2	3	2	2	3	3	1	3	3	3	3	2	3	2	2	3	3	3	3	2	3
QMRW	1.00	0.80	0.75	1.00	1.00	0.70	1.00	0.80	0.65	0.65	1.00	1.00	1.00	0.80	0.80	1.00	0.80	0.80	0.80	0.80	0.80	0.45	1.00	0.80	0.40	0.45	0.80	0.30	0.60	0.40
	1	2	3	1	1	4	1	2	5	5	1	1	1	2	2	1	2	2	2	2	2	7	1	2	8	7	2	9	6	8
QAE	0.92	0.84	0.76	0.84	0.72	0.76	0.72	0.64	0.76	0.72	0.50	0.56	0.68	0.64	0.52	0.60	0.52	0.44	0.50	0.40	0.44	0.64	0.32	0.36	0.48	0.45	0.36	0.56	0.40	0.36
	1	2	3	2	4	3	4	6	3	4	10	8	5	6	9	7	9	13	10	14	13	6	16	15	11	12	15	8	14	15
QIE	1.00	1.00	1.00	1.00	0.60	1.00	1.00	0.80	1.00	1.00	0.80	0.80	0.60	0.60	0.60	0.80	0.40	0.60	0.60	0.25	0.60	0.60	0.60	0.25	0.40	0.45	0.40	0.60	0.40	0.40
	1	1	1	1	3	1	1	2	1	1	2	2	3	3	3	2	5	3	3	6	3	3	3	6	5	4	5	3	5	5
QGE	0.80	0.90	0.80	0.77	0.73	0.70	0.57	0.60	0.80	0.65	0.67	0.50	0.60	0.57	0.40	0.40	0.43	0.67	0.50	0.25	0.43	0.50	0.50	0.30	0.40	0.45	0.25	0.43	0.40	0.47
	2	1	2	3	4	5	9	8	2	7	6	10	8	9	14	14	13	6	10	16	13	10	10	15	14	12	16	13	14	11
QPTE	0.80	0.80	0.75	0.65	0.60	0.70	0.55	0.63	0.65	0.65	0.53	0.45	0.43	0.55	0.40	0.27	0.27	0.43	0.50	0.25	0.27	0.47	0.27	0.25	0.40	0.45	0.25	0.33	0.25	0.37
	1	1	2	4	6	3	7	5	4	4	8	11	12	7	13	16	16	12	9	17	16	10	16	17	13	11	17	15	17	14
QPE	1.00	1.00	1.00	1.00	1.00	0.70	0.60	0.40	1.00	0.80	0.60	0.60	0.80	0.60	0.60	0.25	0.40	0.60	0.50	0.60	0.20	0.45	0.60	0.25	0.40	0.45	0.60	0.60	0.40	0.25
	1	1	1	1	1	3	4	7	1	2	4	4	2	4	4	8	7	4	5	4	9	6	4	8	7	6	4	4	7	8
TOTAL RANK	27	29	44	50	61	63	64	66	72	73	81	82	96	97	107	113	115	116	118	124	127	127	136	138	148	148	160	164	174	185
Efficiency	0.88	0.83	0.78	0.79	0.75	0.72	0.75	0.72	0.71	0.71	0.68	0.68	0.65	0.61	0.61	0.61	0.58	0.57	0.55	0.56	0.55	0.53	0.52	0.52	0.47	0.46	0.43	0.40	0.41	0.32

If we compare these results with ALP (Table 37 and Figure 59) we see some changes in the companies ranking order. Only companies K.4 (1st position), K.6 (7th), K.5 (12th), K.2 (16th) and W.1 (30th) remain in the same positions. All the other companies shift their positions: 8 companies shift their position in one place; 9 in two places; 3 in three places; 2 in four places, and; 2 in five places. Only one company (W.6) shifts its position in seven places: this company was ranked in the 13th position using the ALP approach; using the quality approach it jumped to the 6th position (with a high level of efficiency). This scenario is not dramatically different from the ALP approach. However, some differences exist. The most important advantage of this approach is to rank companies against a quality strategy.

Table 37 - Quality approach vs. ALP

	Efficiency	Rank	ALP	Rank		Efficiency	Rank	ALP	Rank
K.4	0.88	1	4.24	1	K.2	0.61	16	2.61	16
Co.8	0.83	2	3.43	4	Cl.3	0.58	17	2.43	19
Co.7	0.78	3	3.34	6	Cl.6	0.57	18	2.68	14
K.7	0.79	4	3.77	2	Co.3	0.55	19	2.01	24
Cl.7	0.75	5	3.55	3	Cl.4	0.56	20	2.03	22
W.6	0.72	6	2.91	13	K.1	0.55	21	2.29	20
K.6	0.75	7	3.31	7	W.4	0.53	22	2.44	18
K.3	0.72	8	3.37	5	Cl.5	0.52	23	2.22	21
Co.5	0.71	9	3.28	8	Cl.2	0.52	24	2.01	25
Co.6	0.71	10	2.98	9	Co.2	0.47	25	1.92	26
Cl.9	0.68	11	2.96	10	W.5	0.46	26	1.76	29
K.5	0.68	12	2.93	12	W.2	0.43	27	1.76	28
Cl.1	0.65	13	2.95	11	W.3	0.40	28	2.01	23
Co.4	0.61	14	2.61	15	Co.1	0.41	29	1.87	27
Cl.8	0.61	15	2.58	17	W.1	0.32	30	1.68	30

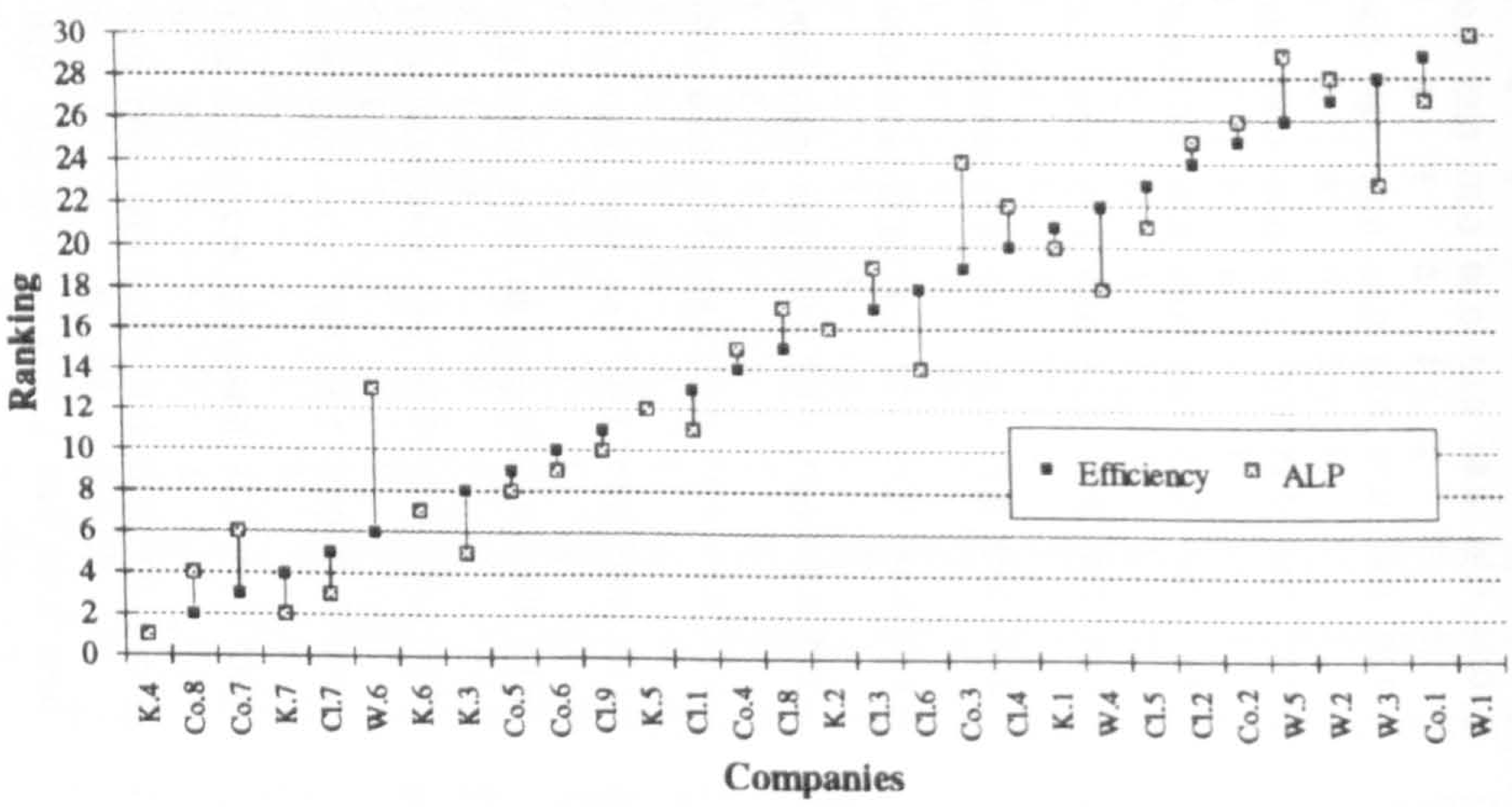

Figure 59 - Quality approach efficiency vs. ALP

5.3.4. The quality-productivity approach

An extension to the approach described in the last section is concerned with the potential correlation that exist between the model variables. A strong correlation was found between the companies quality systems and their productivity. Table 33 showed these variables efficiencies (QPE) for each company. Now, it would be interesting to know which further factors should be taken into account. Therefore, it is required to perform a correlation analysis between the model variables and the QPE efficiency. Table 38 shows the value of the correlation in descending order of strength.

Table 38 - Correlation of factors with QPE efficiency

		Correlation
G	Technologies	0.77
ALP	Average level of performance	0.74
A	Anthropocentrics	0.74
PT	Production techniques	0.72
Q1	Quality System	0.67
Q3	Failure costs	-0.67
I1	N. of new products launched	0.66
Q2	Material scrap	-0.66
C3	V.A./employee	0.60
C4	Production costs/employee	0.56
F	Flexibility	0.46
Q4	Quality costs	-0.46
C1	Raw material in warehouse	-0.44
T4	Waste time	-0.43
C2	Work-in-process	-0.40
T3	Time to introduce new products	-0.38
D3	Average lateness of delivery	-0.36
PR1	Output rate/employee	0.23
D1	Timeliness of delivery	-0.19
T1	Cycle time	0.17
T2	Setup time	-0.16
D2	Delivery lead time	-0.06
T5	Materials residence in warehousing	0.04

It cannot be concluded that a factor influences performance from the observation of a high statistical correlation alone. There must also be a logical causal relationship to explain why the factor influences performance. The rejection of the existence of a causal relationship should be based on a logical explanation of the statistical relationship. From Table 38 it is apparent the high correlation between "technologies", "anthropocentric issues", and "production techniques" (all of them are input factors) with QPE. A high correlation with "technologies" and "production techniques" was expected as the process of assessing these variables depended on existing procedures to assure its effectiveness. Hence higher efficiency is associated with better use of technology and production techniques. The high correlation with "anthropocentric issues" is also attributable to the fact that for any company, the efficiency increases if there is an adequate support from anthropocentric related issues. The correlation with

"Number of new products launched" is also high, but this factor may be influenced by other factors. The next high correlated factors are "failure costs" and "material scrap". Causal relationships here can be identified, but these relationships cannot be attributed to the correlation between "quality assurance system" and "productivity". This situation implies a further analysis. To determine the impact of "failure costs" the principles of Data Envelopment Analysis will be used again.

At this stage it is important to note that we are dealing with two outputs ("productivity" and "failure costs") and one input ("quality assurance system"). It means that we are trying to assess efficiency where two distinct outputs are "produced" from a single input. Figure 60 shows the graphical representation of this situation where each of these two outputs divided by the input are plotted. (The boundary formed by the straight line joining the two companies, Cl.1 and W.2, together with horizontal and vertical lines, envelops the remaining companies in a manner such that any point on the boundary performs better than any point within the boundary).

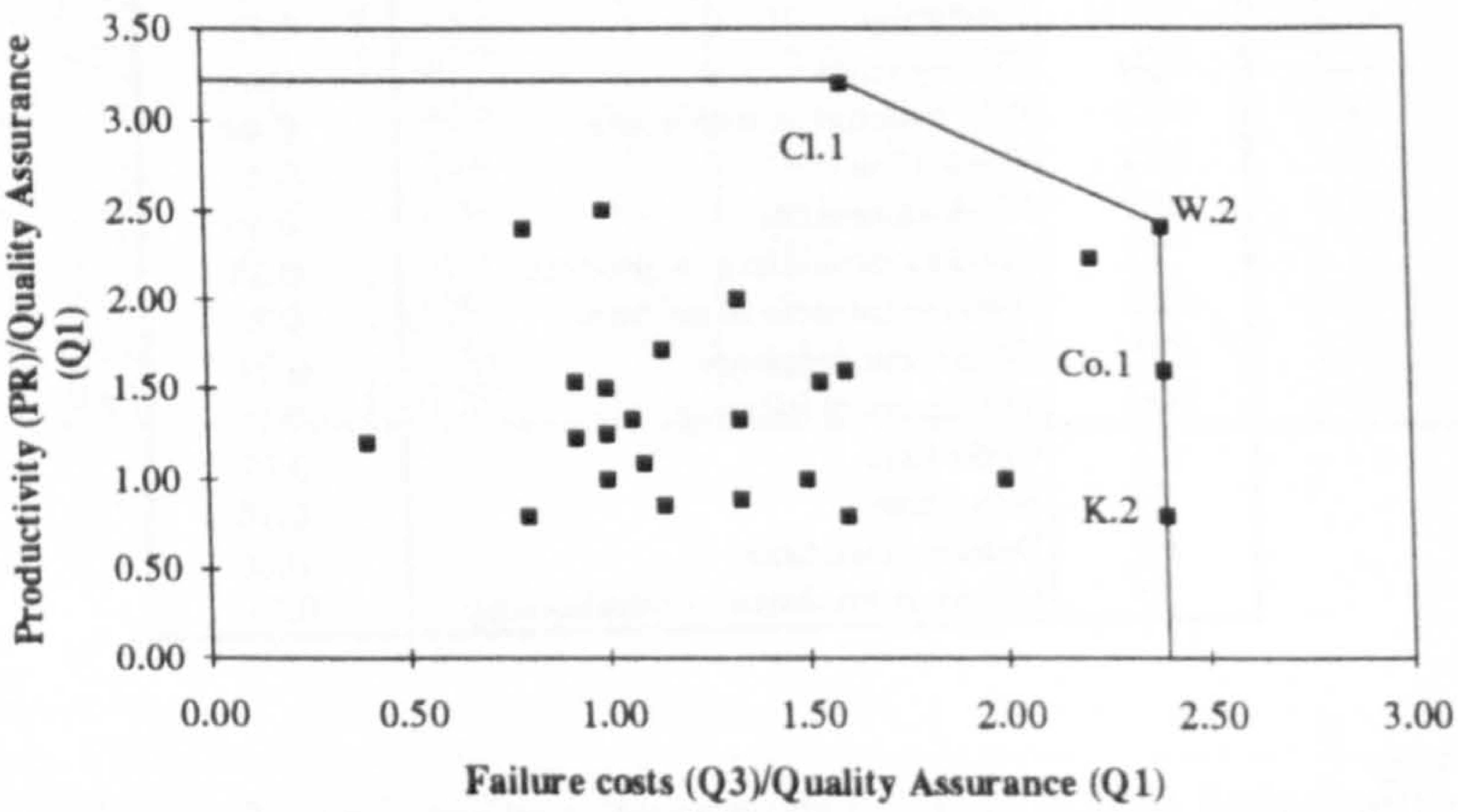

Figure 60 - Q3/Q1 vs. PR/Q1

Table 39 shows the efficiencies between Q3/Q1 and Pr/Q1 (the companies are ranked by descending order of efficiency). Using the same procedure we can go further and a new correlation analysis between these efficiencies and the other factors are presented in Table 40. In this table it is evident that the most correlated factor is "production costs/employee" with 0.50. All the other factors present very low levels of correlation (lower than 0.40). A similar analysis, using "material scrap" (as the other most correlated factor) led to a similar result.

Table 39 - Rankings of Q3/Q1 vs. PR/Q1 ratio values

	Rank	Q3/Q1	Pr/Q1	Efficiency		Rank	Q3/Q1	Pr/Q1	Efficiency
W.2	1	2.40	2.40	1.00	W.4	13	1.33	0.89	0.56
Co.1	1	2.40	1.60	1.00	W.5	14	1.33	0.89	0.56
K.2	1	2.40	0.80	1.00	K.5	15	1.33	1.33	0.56
Cl.1	1	1.60	3.20	1.00	Cl.8	16	1.00	1.50	0.52
K.4	2	2.22	2.22	0.93	K.7	17	0.92	1.54	0.51
K.1	3	2.00	1.00	0.83	Co.7	18	1.07	1.33	0.50
Cl.7	4	1.00	2.50	0.78	W.6	19	1.14	0.86	0.48
Cl.4	5	0.80	2.40	0.75	Co.8	20	1.00	1.25	0.47
Cl.5	6	0.80	2.40	0.75	Co.4	21	1.09	1.09	0.45
W.3	7	1.33	2.00	0.69	K.6	22	1.09	1.09	0.45
Cl.2	8	1.60	0.80	0.67	Co.6	23	0.92	1.23	0.45
Cl.3	9	1.60	1.60	0.67	Co.2	24	1.00	1.00	0.42
Co.5	10	1.54	1.54	0.64	Cl.9	25	0.40	1.20	0.38
K.3	11	1.50	1.00	0.63	W.1	26	0.80	0.80	0.33
Cl.6	12	1.14	1.71	0.60	Co.3	27	0.80	0.80	0.33

Table 40 - Correlation of factors with Q3/Q1 vs. PR/Q1 efficiency

		Correlation
Q1	Quality System	-0.58
C4	Production costs/employee	0.50
T1	Cycle time	-0.37
Q4	Quality costs	-0.34
T5	Materials residence in warehousing	-0.34
D1	Timeliness of delivery	-0.29
T4	Waste time	-0.29
PR1	Output rate/employee	0.25
C1	Raw material in warehouse	-0.24
D2	Delivery lead time	-0.23
PT	Production techniques	-0.22
T2	Setup time	-0.22
I1	N. of new products launched	-0.22
C2	Work-in-process	0.21
G	Technologies	-0.18
C3	V.A./employee	0.16
F	Flexibility	0.13
Q3	Failure costs	-0.08
A	Anthropocentrics	-0.07
Q2	Material scrap	-0.03
ALP	Average level of performance	-0.03
T3	Time to introduce new products	-0.02
D3	Average lateness of delivery	0.02

This analysis shows that the main factors to consider in a quality-productivity approach are "technology", "production techniques", "anthropocentric issues", "number of new products launched", "failure costs", "material scrap", "value added/ employee", and "production costs/employee", and suggests that the later desires a specific analysis.

5.3.5. The value added - production cost approach

The findings from the previous section suggest that it would be interesting to analyse the situation from a value added - production cost perspective. If we consider the ratio between these variables an efficiency can be calculated for each company. Table 41 shows the companies by descendent order of VAPCE efficiency.

Table 41 - Value added / Production cost Efficiency (VAPCE)

	Rank	C3/C4	Efficiency		Rank	C3/C4	Efficiency
K.7	1	0.72	1.00	Cl.1	16	0.54	0.75
K.4	2	0.68	0.94	K.2	17	0.54	0.75
K.6	3	0.68	0.94	Co.6	18	0.53	0.74
Cl.9	4	0.67	0.93	Cl.5	19	0.53	0.73
Cl.7	5	0.67	0.93	Co.4	20	0.52	0.72
Cl.6	6	0.66	0.92	Co.3	21	0.51	0.70
Co.8	7	0.60	0.83	W.5	22	0.49	0.68
Cl.8	8	0.60	0.83	W.4	23	0.49	0.68
Co.7	9	0.60	0.83	K.1	24	0.48	0.67
K.5	10	0.57	0.79	Co.2	25	0.47	0.66
K.3	11	0.56	0.77	Cl.2	26	0.47	0.64
Cl.4	12	0.55	0.76	Co.1	27	0.45	0.63
Cl.3	13	0.55	0.76	W.3	28	0.45	0.63
W.6	14	0.55	0.76	W.2	29	0.42	0.58
Co.5	15	0.55	0.76	W.1	30	0.40	0.55

Figure 61 illustrates the graphical representation of all the companies. The company K.7 presents the highest value added/production cost efficiency. This ratio was used to generate a measure of the other companies' efficiencies by comparing them directly to K.7, which has an efficiency value of 1. The other efficiencies are obtained by dividing all companies' ratios by K.7 ratio.

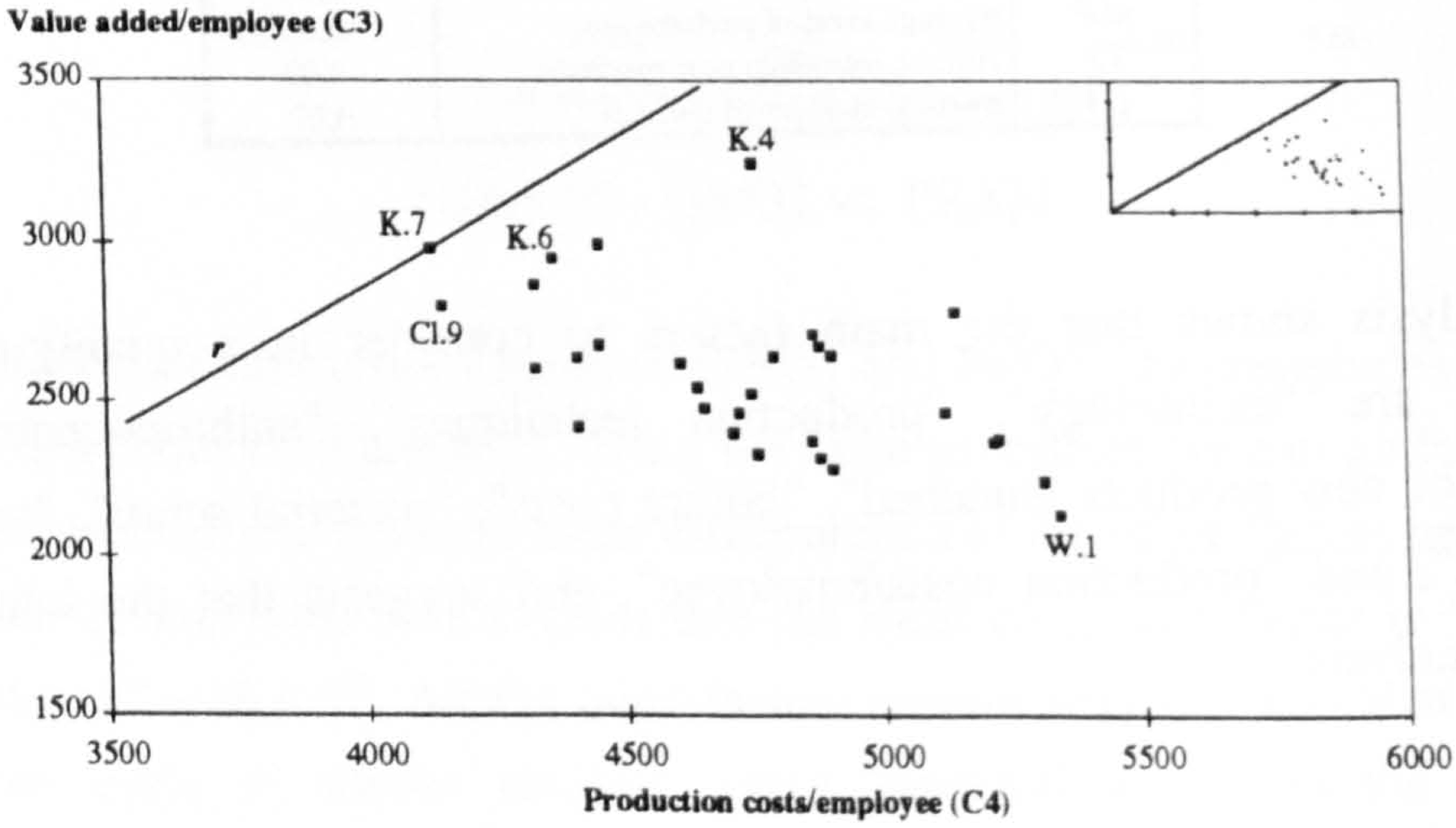

Figure 61 - Value added / Production cost Efficiency (VAPCE)

To find other factors which influences the performance of this efficiency measure a correlation analysis between the model variables and the VAPCE efficiency can be performed. Table 42 shows the values of the correlation in descending order of strength. This analysis shows that most factors have relative high correlation with VAPCE efficiency.

Table 42 - Correlation of factors with VAPCE

		Correlation
C3'	V.A./employee	0.92
C4	Production costs/employee	-0.84
ALP	Average level of performance	0.83
F	Flexibility	0.76
C1'	Raw material in warehouse	-0.75
PR'	Output rate/employee	0.72
PT	Production techniques	0.70
G	Technologies	0.68
T2'	Setup time	-0.66
I1'	N. of new products launched	0.63
T3	Time to introduce new products	-0.63
T4'	Waste time	-0.62
C2'	Work-in-process	-0.62
D3'	Average lateness of delivery	-0.62
A	Anthropocentrics	0.58
Q2'	Material scrap	-0.51
T5	Materials residence in warehousing	-0.50
Q1	Quality System	0.46
D1'	Timeliness of delivery	-0.45
Q4	Quality costs	0.33
T1	Cycle time	-0.28
D2	Delivery lead time	-0.27
Q3	Failure costs	-0.23

Considering only the output factors (C3, C1, PR, T2, I1, T4, C2, D3, Q2, and D1), all of them have a correlation higher then 0.45. This situation suggested establishing relationships between each of these output factors divided by "production costs/employee" ($output_i/input_1$) and the C3/C4 ($output_1/input_1$) ratio. An example of this procedure is illustrated in Table 43 and Figure 62. In this case, the output "productivity" is tested against the input "production cost". Company K.7 presents the best efficiency. The application of data envelopment analysis allows the evaluation of the other companies' efficiencies.

Table 43 - Rankings of PR/C4 vs. C3/C4 ratio values

	Rank	PR/C4	C3/C4	Efficiency		Rank	PR/C4	C3/C4	Efficiency
K.7	1	1.11	0.72	1.00	W.6	16	0.52	0.55	0.76
K.4	2	1.01	0.68	0.95	Co.5	17	0.52	0.55	0.76
K.6	3	0.98	0.68	0.94	K.2	18	0.65	0.54	0.75
Cl.9	4	1.01	0.67	0.94	Co.6	19	0.56	0.53	0.74
Cl.7	5	1.01	0.67	0.93	Co.4	20	0.47	0.52	0.72
Cl.6	6	0.97	0.66	0.92	Co.3	21	0.45	0.51	0.71
Cl.8	7	0.95	0.60	0.86	W.5	22	0.42	0.49	0.68
Co.8	8	0.58	0.60	0.83	W.4	23	0.43	0.49	0.68
Co.7	9	0.57	0.60	0.83	K.1	24	0.70	0.48	0.67
K.5	10	0.91	0.57	0.82	Co.2	25	0.41	0.47	0.66
Cl.5	11	0.91	0.53	0.82	Cl.2	26	0.71	0.47	0.65
K.3	12	0.84	0.56	0.77	Co.1	27	0.36	0.45	0.63
Cl.4	13	0.86	0.55	0.77	W.3	28	0.42	0.45	0.63
Cl.1	14	0.86	0.54	0.77	W.2	29	0.41	0.42	0.59
Cl.3	15	0.80	0.55	0.76	W.1	30	0.34	0.40	0.56

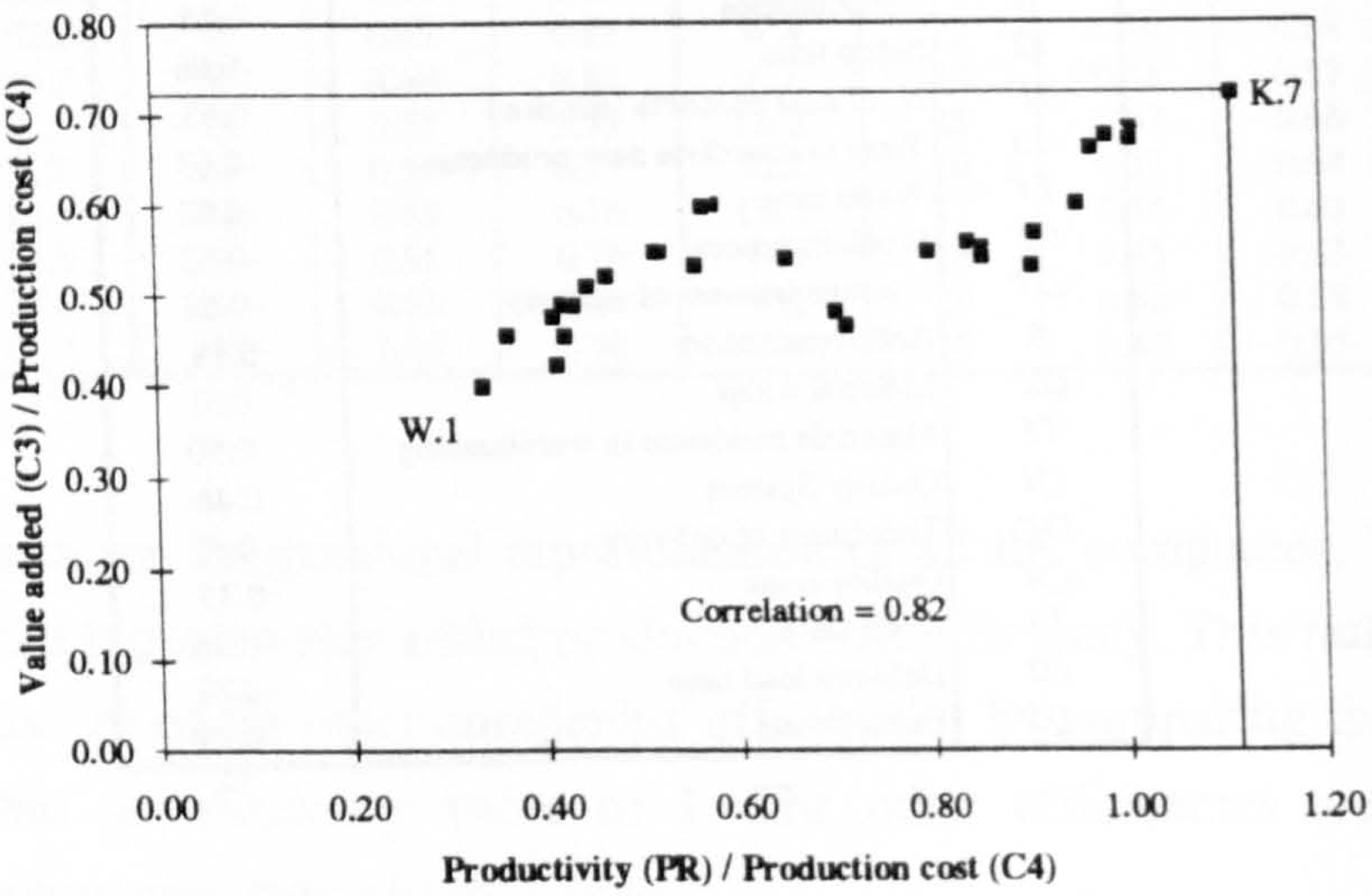

Figure 62 - PR/C4 vs. C3/C4

Table 44 shows the efficiencies as well as the companies' ranking for each efficiency. The last column shows the total rank by ascending order (which means decreasing performance). The final efficiency is calculated as the average of all the other efficiencies.

Comparing these results with those from Table 36 identified some differences between companies ranking. Figure 63 shows major differences in eight companies that changed their relative position in the ranking by 5 to 8 places. In two cases this difference amounted to 12 (Co.7) and 15 (W.6) places.

Table 44 - Rankings of ratio values

(Production cost/employee as model input)

	Rank	C3	Rank	C1	Rank	PR	Rank	T2	Rank	I1	Rank	T4	Rank	C2	Rank	D3	Rank	Q2	Rank	D1	Rank	Final Efficiency
K.4	2	0.94	1	1.00	2	0.95	1	1.00	2	0.95	2	0.98	1	1.00	6	0.60	1	1.00	1	1.00	19	0.94
K.7	1	1.00	4	0.83	1	1.00	3	0.92	1	1.00	3	0.75	2	0.60	10	0.44	2	0.46	9	0.18	36	0.72
Cl.7	5	0.93	2	0.86	5	0.93	2	0.92	5	0.93	5	0.65	5	0.36	3	0.74	4	0.36	11	0.17	47	0.69
K.6	3	0.94	3	0.85	3	0.94	4	0.91	3	0.94	4	0.74	3	0.47	16	0.36	7	0.32	5	0.23	51	0.67
K.3	11	0.77	15	0.67	12	0.77	12	0.42	11	0.77	6	0.59	4	0.46	1	1.00	9	0.30	3	0.28	84	0.60
Cl.9	4	0.93	5	0.78	4	0.94	11	0.43	4	0.94	20	0.35	7	0.35	4	0.69	8	0.31	20	0.11	87	0.58
Co.8	7	0.83	13	0.68	8	0.83	18	0.20	7	0.83	7	0.56	8	0.34	2	0.96	15	0.27	18	0.11	103	0.56
Cl.8	8	0.83	8	0.74	7	0.86	6	0.82	8	0.83	21	0.34	13	0.31	7	0.49	14	0.27	19	0.11	111	0.56
K.2	17	0.75	12	0.71	18	0.75	13	0.41	17	0.75	1	1.00	18	0.27	12	0.39	26	0.20	2	0.33	136	0.56
K.5	10	0.79	11	0.73	10	0.82	14	0.40	10	0.79	10	0.50	10	0.32	5	0.64	6	0.34	6	0.20	92	0.55
Cl.1	16	0.75	6	0.77	14	0.77	5	0.86	16	0.75	9	0.53	19	0.27	19	0.29	12	0.29	8	0.19	124	0.55
Cl.6	6	0.92	7	0.75	6	0.92	10	0.44	6	0.92	13	0.39	11	0.31	18	0.30	18	0.25	13	0.15	108	0.54
Cl.4	12	0.76	9	0.73	13	0.77	8	0.81	12	0.76	18	0.36	22	0.26	20	0.28	21	0.23	4	0.27	139	0.52
Cl.3	13	0.76	14	0.68	15	0.76	7	0.82	13	0.76	22	0.34	15	0.28	11	0.39	23	0.22	15	0.13	148	0.51
Co.7	9	0.83	10	0.73	9	0.83	17	0.20	9	0.83	12	0.44	6	0.35	13	0.39	5	0.34	14	0.14	104	0.51
Co.5	15	0.76	16	0.66	17	0.76	19	0.20	15	0.76	11	0.48	17	0.28	8	0.47	13	0.28	7	0.20	138	0.48
Co.6	18	0.74	20	0.59	19	0.74	22	0.15	18	0.74	8	0.54	9	0.33	9	0.46	10	0.29	25	0.08	158	0.47
Cl.5	19	0.73	22	0.59	11	0.82	15	0.39	19	0.74	15	0.38	30	0.17	14	0.37	24	0.22	23	0.10	192	0.45
Cl.2	26	0.64	18	0.60	26	0.65	9	0.70	26	0.65	14	0.38	25	0.24	23	0.24	27	0.20	17	0.12	211	0.44
K.1	24	0.67	17	0.66	24	0.67	16	0.38	24	0.67	16	0.37	14	0.29	15	0.36	25	0.21	16	0.13	191	0.44
W.6	14	0.76	19	0.60	16	0.76	21	0.19	14	0.76	17	0.37	16	0.28	24	0.22	3	0.37	28	0.07	172	0.44
Co.4	20	0.72	21	0.59	20	0.72	20	0.19	20	0.72	23	0.31	12	0.31	17	0.36	17	0.25	12	0.15	182	0.43
Co.2	25	0.66	26	0.51	25	0.66	29	0.09	25	0.66	25	0.23	21	0.26	22	0.24	16	0.25	10	0.18	224	0.37
Co.3	21	0.70	27	0.49	21	0.71	25	0.12	21	0.71	24	0.26	24	0.25	25	0.22	28	0.18	24	0.09	240	0.37
W.4	23	0.68	23	0.58	23	0.68	24	0.15	23	0.68	28	0.20	20	0.26	27	0.18	20	0.23	22	0.10	233	0.37
Co.1	27	0.63	24	0.55	27	0.63	23	0.15	27	0.63	19	0.36	27	0.21	21	0.25	19	0.23	26	0.08	240	0.37
W.5	22	0.68	28	0.49	22	0.68	27	0.12	22	0.68	29	0.20	26	0.23	26	0.19	22	0.22	27	0.08	251	0.36
W.3	28	0.63	25	0.54	28	0.63	26	0.12	28	0.63	26	0.22	23	0.25	30	0.12	29	0.18	30	0.06	273	0.34
W.2	29	0.58	29	0.48	29	0.59	30	0.09	29	0.59	27	0.21	28	0.20	28	0.17	11	0.29	21	0.10	261	0.33
W.1	30	0.55	30	0.44	30	0.56	28	0.11	30	0.56	30	0.17	29	0.19	29	0.13	30	0.16	29	0.06	295	0.29

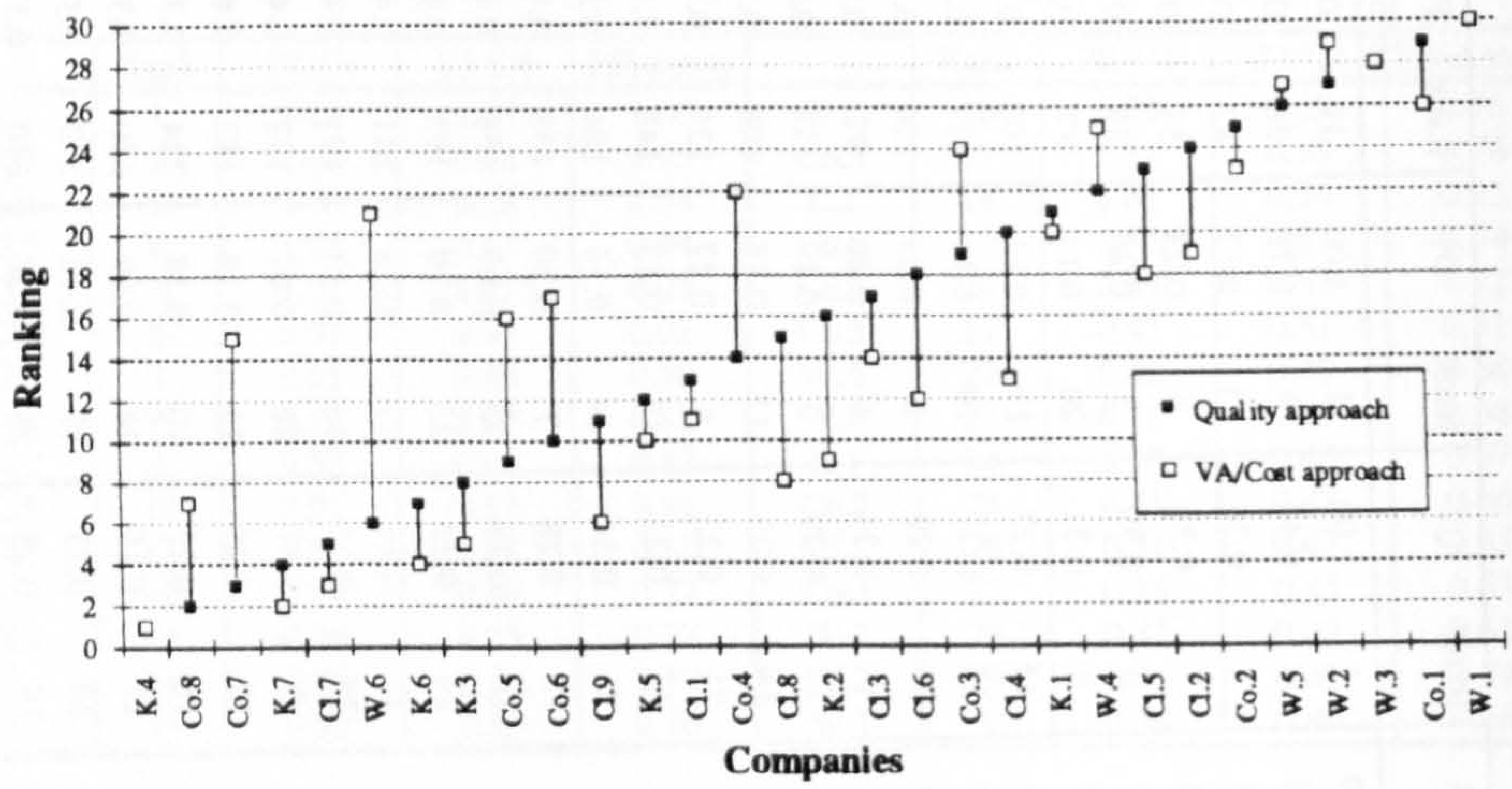

Figure 63 - Quality approach vs. V.A./Cost approach

5.4. Analysis and discussion of results

Performance appears to be influenced by the activity sub-sector the company is in (Table 27). Cotton and knitting sub-sectors present higher ALP values, as well as higher quality systems organisation. In the cotton sub-sector, the quality system organisation variable is above the average of the other variables, which means that it gave a significant contribution to ALP. In the knitting sub-sector there is an opposite situation: the quality system organisation variable gave a negative effect to the global sub-sector performance, as it is lower than the ALP value.

The clothing sub-sector presents a similar situation to the knitting sub-sector: the low value of the quality system organisation value gave a significant negative contribution to ALP. Finally, the wool sub-sector presents the lower quality system organisation and ALP values. It appears that the quality system organisation does not affect the ALP value. In this sub-sector there was an exception: company W.6 had a high value of quality system organisation; although this value affected the ALP, it is still lower than the average ALP for the knitting sub-sector. Two types of reasons explain this situation: the wool sub-sector is an old and traditional sub-sector (most of the companies are based in a familiar ownership), and most of its companies are concentrated in a less well developed region of the country (communications are difficult, and access to new technologies and education only recently have been happening).

The use of the quality approach in section 5.3.3 allowed a better understanding of how companies are performing in the context of Lean Manufacturing. This situation is similar to that identified by the ALP approach, but the differences between companies, and sub-sectors, are clearer. The knitting sub-sector presents the better average efficiency: 4 companies (out of 7) were ranked in the first eight positions. The cotton sub-sector presents the second best average efficiency: 4 companies (out of 8) were ranked in the first ten positions; but two companies were in the last five positions. The clothing sub-sector is in the third position: 8 companies (out of 9) were ranked between the eleventh and the twenty fourth position, with efficiencies between 0.68 and 0.52; this means a high degree of uniformity among these companies. The wool sub-sector was ranked in the last position: 5 companies (out of 6) were in the last nine positions.

The quality approach proposed had the advantage to rank companies against a quality strategy. The extensions presented in sections 5.3.4. and 5.3.5. allowed further detailed analyses. The selection of the ways to follow depends on what one wants to measure. They are not standard. They depend on the definition of a specific strategy. A quality-productivity strategy was chosen, and it was followed by a cost strategy. The results obtained enhance the position of the knitting sub-sector in first place (6 out of 7 companies in the first 10 positions), and the wool sub-sector in the last place (all the 6 companies in the last ten positions). The cotton sub-sector (3 companies in the first 15 positions), and the clothing sub-sector (7 companies in the first 15 positions) shifted their relative positions.

In terms of company size it was found that the larger companies of the wool and cotton sub-sectors, and the medium sized companies of the knitting and clothing sub-sectors, were ranked in better positions.

In these companies people appear to think of themselves as a part of the system. They were aware of the company objectives, they felt themselves responsible for the quality, and continuous improvement was evident. However, the results show that the main obstacles to adopt Lean Manufacturing in the textile and clothing industry are common to all the companies: the supplier chain is not systematically involved in the product development; lack of organisation flexibility and empowerment; lack of quality systems organisation.

This scenario shows that the adoption of Lean Manufacturing by the textile and clothing industry is not well developed. Younger sub-sectors, with medium sized companies, tend to perform better in the context of Lean Manufacturing (ex: the knitting sub-sector). Sub-sectors, where the market demands sophisticated advanced technology and product quality (ex: the cotton sub-sector), or fast lead times and deliveries (ex: the clothing sub-sector), are trying to apply Lean Manufacturing objectives. Older sub-sectors (ex: the wool sub-sector), and traditional companies, tend to resist change in their work practices needed to adopt Lean Manufacturing.

The next Chapter derives quality system specifications to facilitate the realisation of Lean Manufacturing.

6. QUALITY SYSTEM REQUIREMENTS FOR LEAN MANUFACTURING

This chapter develops and defines new quality system requirements for Lean Manufacturing, based on the model formulation and results from previous chapters. It addresses the need for new quality tools.

6.1. The new Quality Lean environment

The Quality Lean environment is the one that fulfils customer expectations. Maintenance of high quality requires conscious efforts in various stages in design and in manufacture. The development of this philosophy in lean companies, should include the interrelationships between the company's community, the supply chain, the product development, and the customer focus (Figure 64).

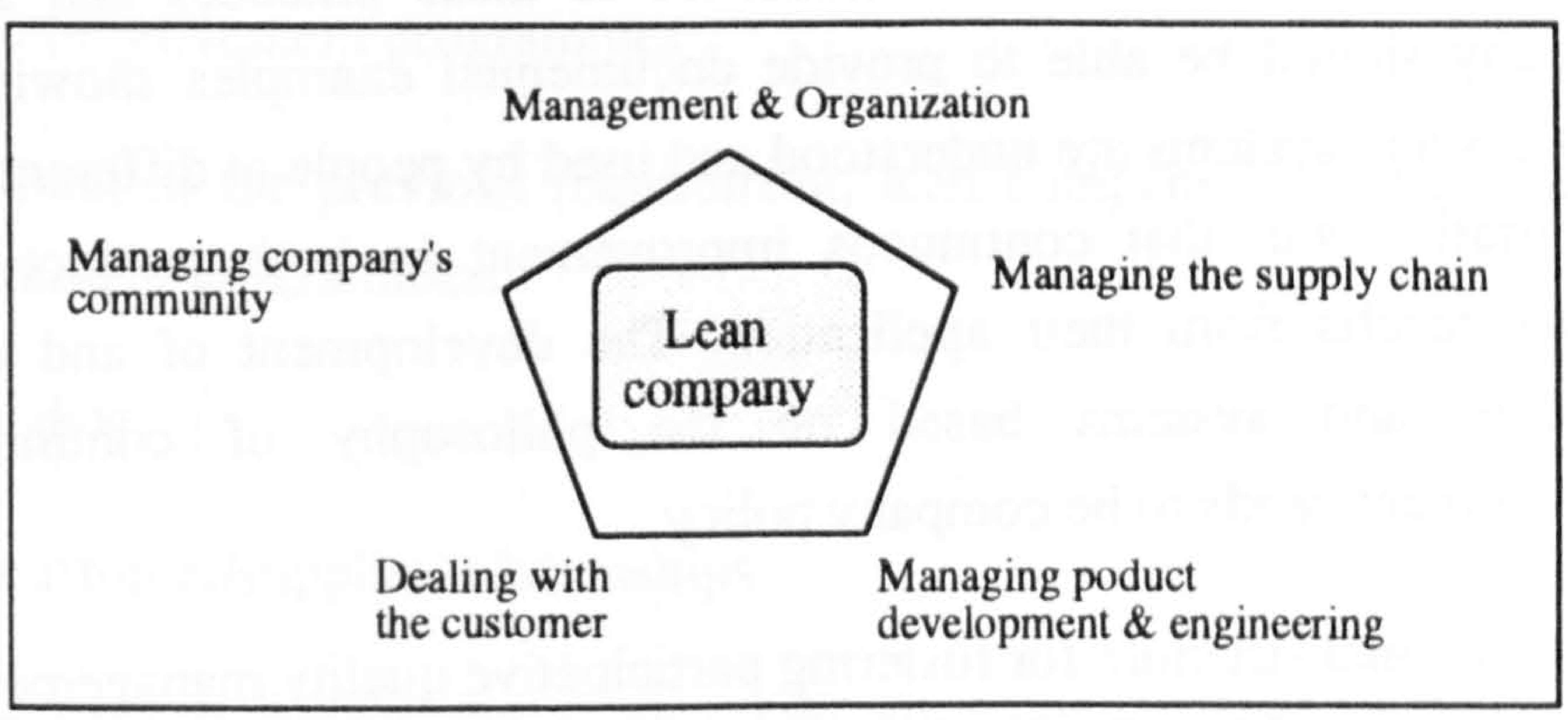

Figure 64 - Main issues in Lean Manufacturing

6.2. Quality System requirements

The implementation of a Lean Manufacturing environment must be done on a systematic and consistent basis. Quality assurance standards have proved to be a useful tool in the implementation of quality systems. It is my opinion that additions must be made to the standards' requirements to adopt Lean Manufacturing effectively. From my earlier work I have extracted insights into some existing quality requirements, namely:

Management responsibility

- Long-term strategic plan and direction

  Lean companies must have a rolling, long-term (three to five years) strategic plan, which not only defines corporate objectives, goals, and operational plans for implementing policies and practices that consistently add value to the company's products and services but also identifies the knowledge, tools, and skills required for effective implementation.

- Top management's commitment, leadership, and adherence to a policy of continuous quality improvement

  Given that continuous improvement is the underlying philosophy of total quality, it is essential that practices and systems supporting this philosophy exist in a lean company and that management provides the resources and support to foster the ongoing development of and adherence to these practices and systems. The company should be able to provide documented examples showing that these practices and systems are understood and used by people at different levels of the organisation and that continuous improvement in both product and process quality results from their application. The development of and adherence to practices and systems based on the philosophy of continuous quality improvement needs to be company policy.

- Organisational structure for fostering participative quality management

  Lean companies must develop their organisational structure to include systematic participation of their employees.

- Communication systems and practices

  Lean companies must recognise the importance of good communication and must strive to establish and maintain simple systems and procedures that provide timely and accurate information flow throughout the company. Providing company personnel with appropriate information in an understandable format is management's responsibility.

- Performance measurement

  Measuring performance and benchmarking company systems and functions should be used to provide vital information for continuous improvement.

Quality system

- The quality manual

  The quality manual should reflect the philosophy of continuous quality improvement through employee involvement and define explicitly the who, what, when, how, and why for all quality procedures.

- Quality system for defect prevention

  In lean companies the quality system must be designed as a prevention tool.

- Measurement of quality improvement

  The quality system should address the measurement of quality improvement in all the processes of the company.

- Quality improvement programmes

  As a result of the previous requirement, lean companies must establish quality improvement programmes.

Contract review

- Closer customer/supplier relationships

  In Lean Manufacturing, the customer/supplier relationships must be reinforced. This situation suggests that this requirement should consider the benefit achieved from improvement efforts developed by both organisations.

Design control

- Customer-driven product development

  Lean companies must focus on customer-driven strategies for product development, emphasising ongoing customer contact and intellectual commitment for defining product concepts and performance and quality specifications.

Determining current and future customer requirements and expectations is a key issue. The management must assure that the "voice of the customer" is heard, communicated throughout the organisation, and acted on in a timely and responsive manner.

- Cross-functional teams for product design

  Lean companies must use cross-functional teams (including design, manufacturing, marketing) for responding to and communicating the needs of the customer throughout the organisation, coupling decisions in product design, materials, and manufacturing process selection to bring better products to the market more quickly.

- Failure mode effect analysis

  Lean companies should perform failure mode effect analysis (FMEA) for new product designs, to provide improved and reliable products.

- Design for manufacture (DFM) procedures

  In Lean Manufacturing, companies should develop DFM procedures to assure that there are no wastes in the manufacturing and assembly processes (due to poor design).

- Concurrent engineering

  Lean companies should adopt concurrent engineering to design and develop a new product faster. Developing design tasks in parallel (simultaneously) requires an adequate design control.

Purchasing

- Partnership-like relationships with suppliers

  Purchasing plays a primarily role in the establishment of good partnerships with external suppliers. For internal suppliers, the receiving department should be responsible for ensuring that the supplier has a quality improvement programme.

  Lean companies must seek out and establish partnership-like relationships (based heavily on non price criteria such as quality and delivery) with one supplier (or a very few) per commodity and seek early vendor involvement in quality improvement and new product development efforts.

- Incoming purchased materials

  Lean companies must assess supplier's capability and capacity to meet contractual agreements.

Process control

- Continuous flow-processing

  Lean companies must focus on standardising, simplifying, and focusing their manufacturing operations and related instructions, thereby reducing complexity and facilitating the effective use of continuous flow processing concepts for reductions in lead times, work-in-process inventories, and materials handling.

- Design layout

  Lean companies must look at and assess systematically its layout and improve it according to their processes.

- Demand based processing

  Lean companies must recognise that adopting an enlarged view of manufacturing operations even at the cost of allowing machines to sit idle some of the time can provide gains in plantwide efficiency and quality.

- Just-In-Time

  Lean companies must be organised to cope with just-in-time production.

- Quick changeover procedures/small lot sizes

  Lean companies must use multidisciplined, multilevel work teams to standardise and simplify changeover procedures, thus reducing equipment downtime during job changeovers and allowing production in smaller lot sizes.

- Emphasis on standardising/simplifying before automating

  Lean companies must view high technology and automation more as complementary tools than as a manufacturing strategy, focusing on standardising, simplifying, and providing the integrity of a manufacturing process before automating.

- Preventive/predictive maintenance

  Lean companies must have a preventive and predictive maintenance programme, typically based on worker involvement efforts, to minimise the occurrence of disruption to the continuous flow of processing.

Inspection and testing

- Emphasis on process control

  The production process must be checked while work is being done. Every workstation should have an inspection point and every worker must be an inspector. Aids such as flowcharts, scatter diagrams, Pareto charts, Fishbone charts, run charts, and statistical control charts should be used.

- Easy-to-see Quality

  The plant should be open to inspection by customer teams and quality testing devices; rooms and environments should be displayed in "understand by a glance" language of charts, displays, and pictures.

- Insistence on compliance

  In Lean Manufacturing the worker should have the authority to stop the production line to correct quality problems. This kind of authority is vital to maintain the quality policy.

- Emphasis on 100% inspection

  Every item should be inspected on a 100% basis. This implies that the workers in the production department are responsible for quality. Rework when required should be performed by the same operator who made the wrong workpiece.

Internal quality audits

- Performance assessment

  Internal audits should be carried out to access the quality system as well as company systems and functions to assure continuous performance improvement.

Training

- Employee involvement and human resource development

  Lean companies must get employees involved at all levels of the organisation and must have extensive training programmes for providing their employees with the knowledge and skills necessary to improve themselves and to understand and implement the many changes and technologies that accompany a philosophy of continuous experimentation and improvement.

- Learning organisation

  In lean companies everybody is expected to participate in the learning, and teaching process. Employees should be empowered to take initiatives of showing to other people how they solved their problems and errors.

Servicing

- Customer relationships

  In Lean companies all departments and functions must be prepared to interface with the customer as they have the responsibility for ensuring that the customer's requirements are being met right the first time.

Statistical techniques

- Lean companies must focus on controlling the process based on statistical measures, and encourage decision making at the operating level using local data sources on key variables for comparisons against customer needs.

Quality costs

- Measurement

  Quality costs evaluation in lean companies should be a mandatory requirement. Its measurement provides vital information for management decisions on the implementation of continuous improvement programmes.

Environmental issues

- Pollution control

  Lean companies must design their manufacturing processes to avoid environmental damages.

- Design for recyclability

  Product design should address recyclability after product utilisation.

Continuous improvement

- In lean companies to make quality is everyone's job responsibility. The quality department should act as a support and co-ordination function for fostering continuous quality improvement throughout the organisation. Lean companies must solicit relationships and establish linkages with university systems, promoting research and educational activities.

- Emphasis on innovation

  Lean companies must be innovative, constantly experimenting to improve existing products and processes, and to develop new ones, striving for less variability and greater capability.

6.3. Quality tools

The advantages of Lean Manufacturing have been identified throughout this thesis. However, its implementation is complex. It should be assisted with quality tools. They are vital enablers to the creation of a mean and Lean Manufacturing environment. The purpose of these tools is to assure *continuous improvement*. Table 45 refers to most important tools. Many researchers report major benefits of using these tools in the introduction of better product and process designs in less time. Areas of application cover all company areas: general management areas, research and development of new products, production and sales, etc.

Table 45 - Quality tools for Lean Manufacturing

Deming [DEM86]	**The Deming approach** Deming's 14 points present an exceptional tool to assure management commitment and quality policy at the execution level.
Dale [DAL90]	**Quality Policy Deployment (QFD)** QFD help to achieve strategic business goals. It ensures that the quality improvement activities are integrated with the organisation's corporate objectives and that each employee is focused on a common direction and takes ownership for improvement.
Gopalakrishnan [GOP92]	**The "house of quality"** The "house of quality" (a QFD tool) is used to implement a quality process that complements the development of products and services. This is a tool to assess performance of products/services and it can be used to help introduce quality improvement into any process in the organisation.
Taguchi [TAG89]	**Taguchi methods** Tagushi methods are used in product development and design. It provides adequate tolerancing to facilitate manufacturing and assembly activities.
Plsek [PLS89]	**Failure Mode Effect Analysis (FMEA)** Failure Mode Effect Analysis (FMEA) is a continuous improvement tool that can be used in the design of new products, services or business process.
Barker [BAR90]	**The 7 Quality tools** The seven quality tools have been adapted from usage in diverse fields: • Relations diagram method • KJ diagram method (affinity diagram method) • Systematic diagram method • Matrix diagram method • Matrix data-analysis method • PDPC (process decision programme chart) method • Arrow diagram method

Lean Manufacturing will only be achieved when all managers and staff are encouraged to contribute towards "quality thinking". Quality thinking should become pro-active rather than re-active. The new quality tools can assist in this way, specifically to promote improvement and to ensure continued motivation to improve.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

The objectives of the research programme have been met. An integrated methodology for creating a Lean Manufacturing environment in the Textile and Clothing Industry has been proposed. Current and potential application of Lean Manufacturing to the Portuguese Textile and Clothing Industry was evaluated. Current business performance assessment criteria, and quality policies practices were determined. The most important variables in modelling for Lean Manufacturing were identified. The methodology was applied and validated in selected industrial test sites. Quality system specifications for Lean Manufacturing were derived.

The adoption of Lean Manufacturing by the Portuguese Textile and Clothing Industry is not well developed. The research revealed a particular set of companies that are achieving Lean Manufacturing objectives. This situation is not uniform for the different industry sub-sectors identified: wool, cotton, knitting, and clothing. Older sub-sectors - wool - and traditional companies, tend to resist change in their work practices needed to adopt Lean Manufacturing. The result has been a generalised business crisis in the most traditional companies of this sub-sector. In the other sub-sectors Lean Manufacturing is beginning to be applied, but without a scientific approach to support it.

The author found that Quality should be considered a top level strategy and that its realisation relates to the performance objectives of the organisation. In his point of view Quality includes all the processes of the organisation. It means that Quality is the envelope for everything that happens in the organisation: it must provide for creating a *mean and lean manufacturing environment*. The research proves that those companies that have implemented quality assurance systems are closer to the Lean Manufacturing objectives. The conclusions are that Lean Manufacturing can be applied to the Textile and Clothing Industry, and that a quality approach is a means to achieve a Lean Manufacturing environment.

Current business performance assessment criteria were found to be based in financial analyses. In addition, traditional assessment of quality assurance performance was found to be inadequate to represent the reality of this new environment. Current quality policies practices showed that quality management and new quality procedures must be developed to achieve it. The author's model for Lean Manufacturing provided a better understanding of the most important variables in the new market environment. It allows the company to adapt itself to this environment. The model uses a broad set of clearly identified variables: objective variables (quality, productivity, delivery, cost, innovation, and time related elements), and subjective variables (flexibility, technological, and anthropocentric elements). The fusion of these variables provided the basis of the modelling process towards a Lean Manufacturing environment. It was designed to assess the company performance from a Lean perspective, and not only from traditional Financial or Quality Assurance perspectives. The model proposed complements traditional procedures for assessing company performance based on financial criteria.

The model development derived from an applied research in 324 companies of the Portuguese Textile and Clothing Industry. A technique based on Data Envelopment Analysis was developed to analyse data from those companies. This technique proved to be a powerful tool for evaluating the performance of comparable organisational units. It assisted quantification of Lean Manufacturing assessment.

Results from the model application can provide important help to establish or update companies strategies, and define main priorities. In addition, the model can be used as a continuous improvement tool.

A widespread understanding that technology was a priority concern was verified. But I concluded that the implementation of a formal quality system as proposed would facilitate and support technological innovation or manufacturing methodology. The introduction of new technologies or manufacturing processes can encounter difficulties in an environment of non quality awareness. The profit obtained through quality would be added to that coming from technical innovation. The author is convinced that this situation is true in most companies involved in this work.

It is notoriously difficult to apply objective measures on this type of research and this work has relied on subjective assessments from the management within the companies. The criteria of feasibility (could it be done), and utility (how useful was it) were applied. The findings are that the process is definitely feasible and all the companies found the approach useful.

This study points out the need to improve the organisation for quality in the Portuguese Textile and Clothing Industry. It should be taken into account in the new restructuring policy of the EC global textile strategy. The solution to overcome EC textile crisis depends on a deep re-dimensioning of the industry and investment in the Quality side of the business. The priority is organisational investment. This will allow the quality system to take advantage of its key role in the creation of the Lean Manufacturing system.

7.2. Recommendations for further work

Two areas for further research were identified and recommended: how to improve customer-supplier relationships in the Textile and Clothing Industry, and how to design optimal performance for Lean Manufacturing.

The customer-supplier chain is an important issue in Lean Manufacturing. This research suggests that customers and suppliers have good relationships. Suppliers were considered the best internal institution to help solving problems with quality. However, there was no evidence that the suppliers were involved in the first phases of product development. A stronger relationship at this stage could lead to faster time-to-market of new products, which is very important in this industry. Further research would be required to identify the obstacles to overcome this situation.

In section 3.4.5. the question of designing optimal performance for Lean Manufacturing was addressed. It was found that current research in this area is not well advanced. The development of Lean Manufacturing, and the potential introduction of new manufacturing paradigms, force the optimisation of all the company systems performance. It is the author opinion that the selection, and prioritisation of the systems to improve depends on a global optimisation analysis. This is a complex problem that requires further research.

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1. Annex - Some characteristics of Portuguese TCIs

1.1. Introduction

In this section an analysis of the main problems of the Portuguese Textile and Clothing Industry (TCI) is carried out. Before doing that, some considerations and observations must be addressed:

- The main problems of the TCIs were identified during the research work. They are related with the following domains:
  - equipment
  - facilities
  - productivity
  - organisation
  - management
  - international competition
  - comparative advantages and disadvantages
  - attitudes towards market needs and trends
- Most problems appointed are similar to other Portuguese industrial sectors. In fact, diagnoses and attitudes from government, industrial associations and entrepreneurial entities, are not substantially different, mainly in those sectors called traditional [MAC92, MAC93];
- The present and future of the Portuguese TCIs present some concern. Declarations and attitudes from government, entrepreneurs and unions show different interpretations, sometimes contradictory, of what to do, how to do it and with what;
- Probably, the deterioration of the situation and the problems identified is a result, among other reasons, of those situations referred to in the last comment;
- Another important issue that must be considered is the change of the community competition. This new environment alerts for the importance to avoid ambiguity of attitudes towards the restructure and modernisation of the TCIs.

1.2. The problems of specialisation and competitiveness

We should point out the main characteristics of specialisation and competitiveness that have affected the Portuguese TCIs. The situation can be summarised as follows:

- Clothing, knitting, home-textiles and non specific textile subsectors are inserted in international specialisation domains, where the kind of specialisation is considered integral or strong, and the orientation towards exportation is followed by a strong internal market coverage;
- Yarn, fabrics and rope manufacturing subsectors were affected by a significant specialisation, characterised by less orientation to exportation;
- Artificial and syntactic fibres subsectors were characterised by a certain dependency and the coverage of the internal market is not enough;
- The presence of foreign capital companies was more significant in the clothing subsector, followed by yarn, fabrics and rope manufacturing subsectors;
- The international specialisation domains in which the subsectors were inserted were considered as fragile (ex: situations of specialisation domains with significant foreign presence - clothing subsector).

The TCI sub-system was considered one of the most important sectors in what concerns international specialisation. It was responsible for a large amount of Portuguese exportations. However, it has suffered a strong demobilisation movement which is a result of the natural drop of international demand.

The growth of the manufacturing of yarn, fabrics and ropes, was less than that related with the manufacturing of finished products like knitting, clothing and home-textiles. Its contribution for exportation was not significant. The production of this subsector was mainly used in the internal market. This means that Portugal is mainly specialised in exporting finished products.

1.3. Advantages and disadvantages of the Portuguese TCIs

In a report from the World Bank [WBA93] about the Portuguese economy, the concept of Revealed Comparative Advantage (RCA) is used. The RCA is based in the presuppose that the trading level of a product reflects differences between countries of relative costs and non-price factors. This "reveals" the comparative advantage of a certain country that has a high success in the exportation of those products. The RCA index is a result of dividing the export share of a certain product of a specific country by the correspondent share of a set of countries (or the world) to whom we want to compare.

Table 46 shows the comparisons of the RCA coefficients and relative positions for the main products of the TCIs, for two groups of countries: a group of 40 developing countries and a group of the industrialised countries. It can be seen that the group of the developing countries is in a better position to supply special textile goods, ropes, cotton goods, and yarn. In opposition, the supply of woman clothes is not well advanced. In what concerns exports to industrialised countries, the RCAs are generally less favourable.

Table 46 - Comparison of RCA coefficients and Relative Positions (RP)

	Comparison with the 40 developing countries				Comparison with the industrialised countries			
	To all destinations		To industria-lized countries		To all destinations		To industria-lized countries	
	RCA	RP	RCA	RP	RCA	RP	RCA	RP
Special textile goods	11.348	3	9.542	4	3.055	15	45.980	2
Cotton goods	2.234	16	2.485	25	3.118	13	7.191	11
Wool goods	1.305	32	1.914	40	-	-	0.863	43
Under wear	1.919	24	1.435	46	-	-	15.130	5
Woman clothes	0.886	49	-	-	-	-	3.210	21
Man clothes	1.814	30	1.359	47	2.527	22	10.354	9
Other clothes	1.829	28	1.302	48	1.335	42	9.678	10
Non-specified textile goods	2.253	17	3.702	16	0.808	58	0.901	39
Yarn	1.704	31	1.973	37	-	-	3.799	17
Textile sacs	1.494	36	2.458	26	3.445	12	4.848	15
Ropes	5.336	7	5.321	9	3.693	10	31.120	3

The comparison with the industrialised countries shows some important differences in RCA, namely in what concerns products that had a good relative position when compared with the 40 developing countries and to all destinations. In general, the situation is favourable for the exportation to all destinations, particularly in terms of special textile products, ropes, under wear and clothes for men.

Table 47 shows a resume of a study about comparative advantages over the EC [PIC90]. This study concludes weak development perspectives for the wool and cotton subsectors. The situation is more favourable in the clothing subsector, namely in terms of development perspectives, with a strong or moderate sensibility level, comparative advantages based on qualified work and positive RCA.

Table 47 - Comparative advantages over EC

WOOL	• Low development perspectives • EC effect tend to increase importation • Productivity growth must be greater than salary increase • Comparative advantages	Strong/moderate level of sensibility Increase of exportations greater than increase of importation Based on natural resources RCA negative, stationary
COTTON	• Low development perspectives • EC effect tend to increase importation • Productivity growth must be greater than salary increase • Comparative advantages	Strong/moderate level of sensibility Increase of importation greater than increase of exportations Based on natural resources RCA positive, stationary
OTHER TEXTILES	• Low development perspectives • EC effect tend to increase importation • Productivity growth must be greater than salary increase • Comparative advantages	Strong/moderate level of sensibility Balanced imports and exports Based on natural resources RCA positive, unfavourable trend
CLOTHING	• Favourable development perspectives • EC effect tend to increase importation • Productivity growth must be greater than salary increase • Comparative advantages	Strong/moderate level of sensibility Based on qualified work RCA positive, favourable trend

Table 48 presents an analysis of southern European competitivity from the view point of demand and competitiveness effects. The demand effect corresponds to the difference between the estimated increase of exports that would happen if those of each product increase at the same rate as the external demand of the same products (which is equivalent to maintaining the share of each country in the world market for each product), and the increase required to maintain constant the share of each country in the world market. The competitive effect corresponds to the difference between the variation of real exports and the sum of the demand effects. From Table 48 one concludes that the demand effect was most negative when comparing Portugal with other European countries. This situation is only overcome by Latin American and Far Eastern countries. In what concerns competitivity effects, the situation is also not favourable. It is only superior to Italy, East Europe and Yugoslavia.

Table 48 - Contribution of demand and competitivity effects for the variations of market share

	Demand	Competitiveness
Portugal	-22.1	12.0
Greece	-13.2	39.0
Spain	-15.3	15.6
Turkey	-9.0	21.7
Yugoslavia	-7.0	-33.0
Italy	-15.1	9.9
Latin America	-37.1	41.8
Far East	-25.2	21.5
North Africa	-17.0	54.0
East Europe	-19.7	0.6
Rest of the World	-18.6	-6.4

In 1990 the cost-hour of salaries of man-power in US dollars in the textile industry were as follows (Table 49):

Table 49 - Salaries per country

	Cost-hour of salaries (US$)		Cost-hour of salaries (US$)
Portugal	3.03	Italy	13.03
R. P. China	0.40	Germany	13.17
India	0.65	Netherlands	14.06
Turkey	1.27	Benelux	13.42
Hong-Kong	2.44	Japan	13.98
South Korea	2.87	United States	9.71
Taiwan	3.36		

1.4. The structure of the Portuguese Textile and Clothing Industries

The analysis of the Portuguese Textile and Clothing Industries suggests the following comments:

- The number of companies operating in the TCIs has stabilised in the last years. However, in the knitting sub-sector there is some reduction of minor importance,
- The number of people working in the TCIs has increased, but slowly. In the clothing sub-sector it has increased with more consistency,

- The gross value of the production has increased at a Annual Growth Mean Rate (AGMR) of 6.5% per year. The situation is quite different for each sub-sector. The knitting sub-sector had the most positive indicator,
- The gross added value has increased at a AGMR of 13%. The clothing sub-sector had the most positive indicator,
- The productivity has increased 11.6%.

In comparison with other industrial sectors it was found that:

- The TCIs were the only industries where the number of companies and man-power did not decrease,
- The TCIs have the lowest growth of the annual gross value of production rate,
- The TCIs have the lowest AGMR of gross added value and productivity.

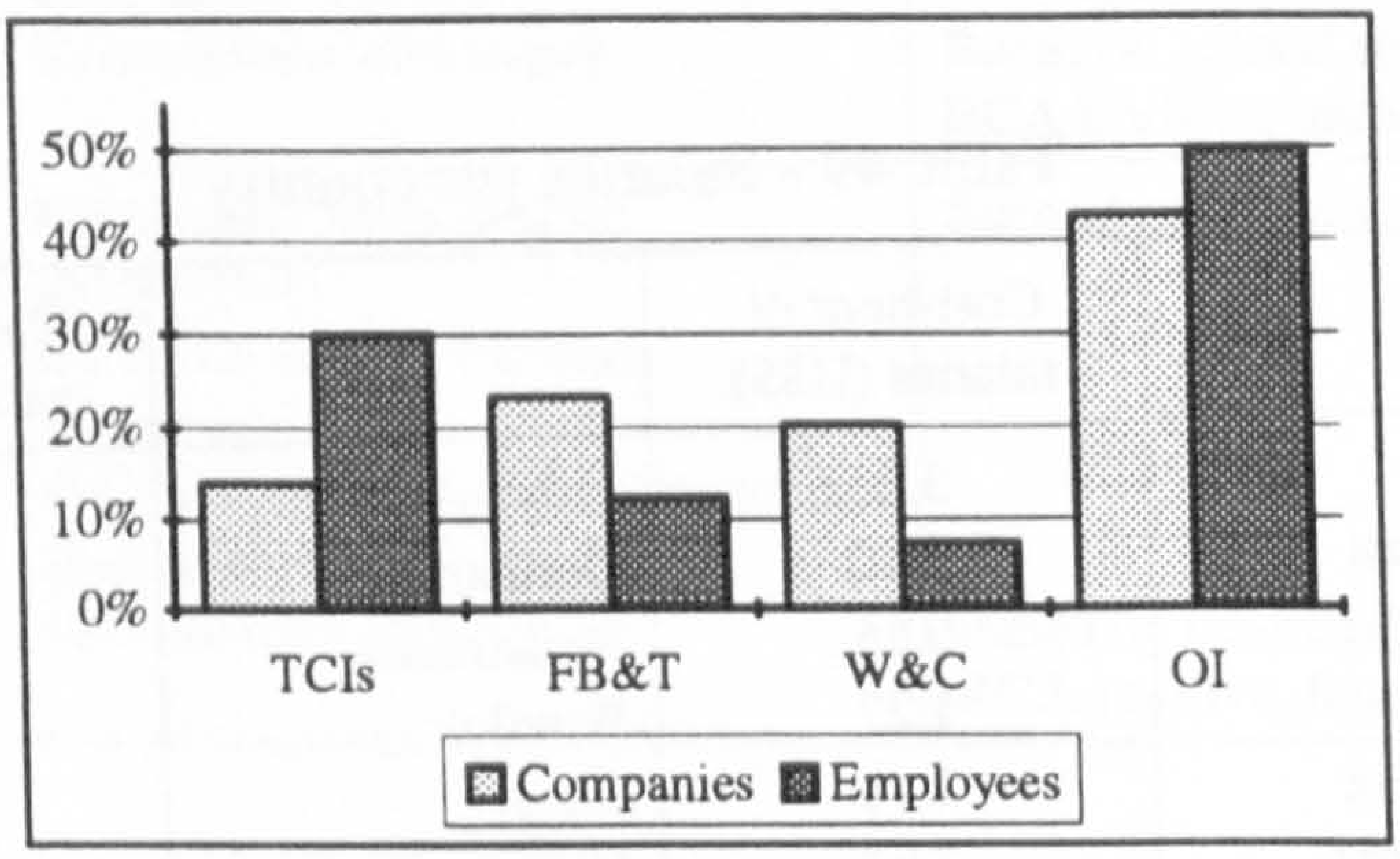

Figure 65 - No. of companies and employees per sector(1)

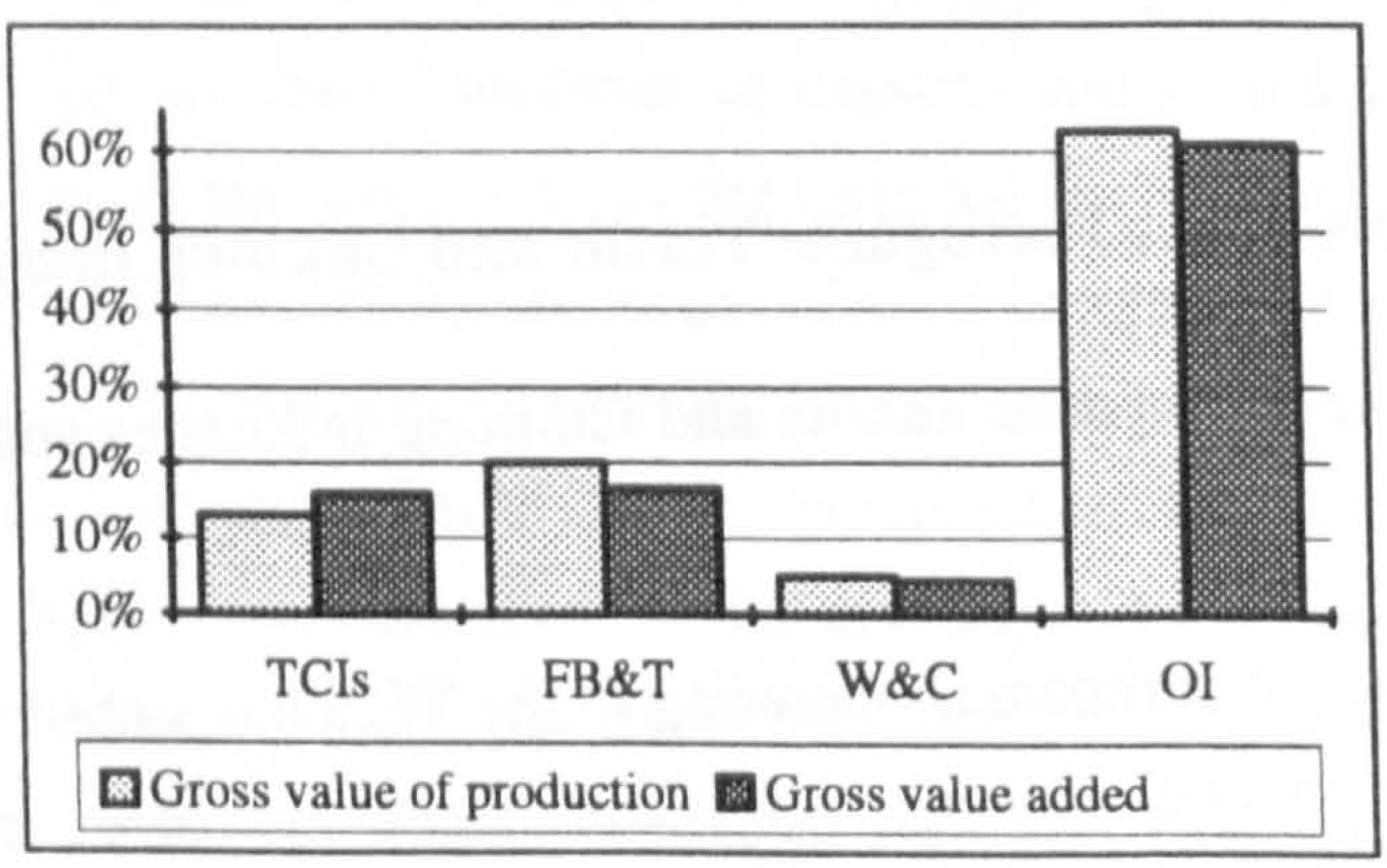

Figure 66 - Gross Value of Production and Gross Value Added(1)

(1) TCIs - Textile & Clothing Industries, FB&T - Food, Beverages & Tobacco, W&C - Wood & Cork, OI - Other Industrial sectors, TOTAL - Total of Industry

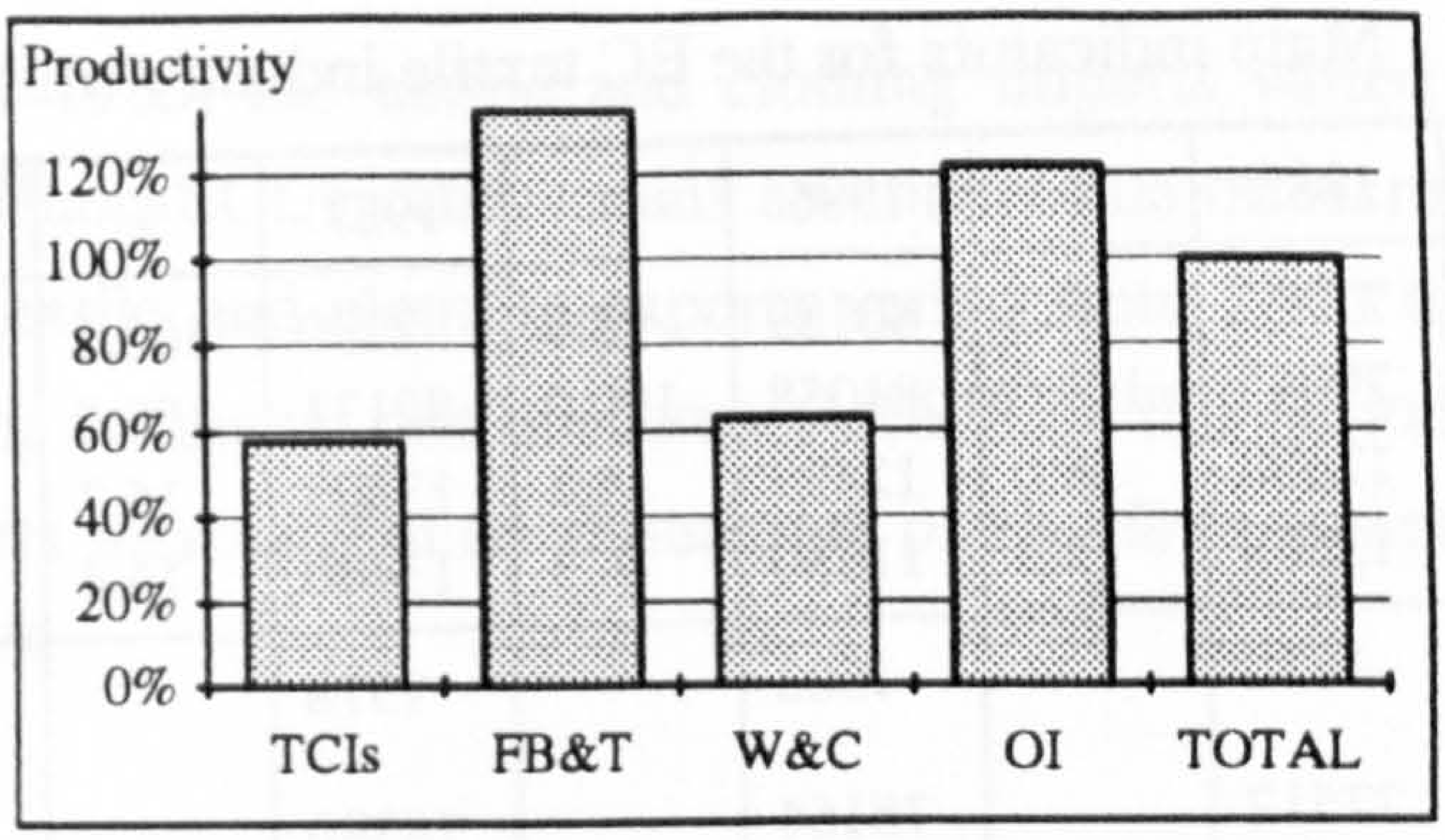

Figure 67 - Productivity(1)

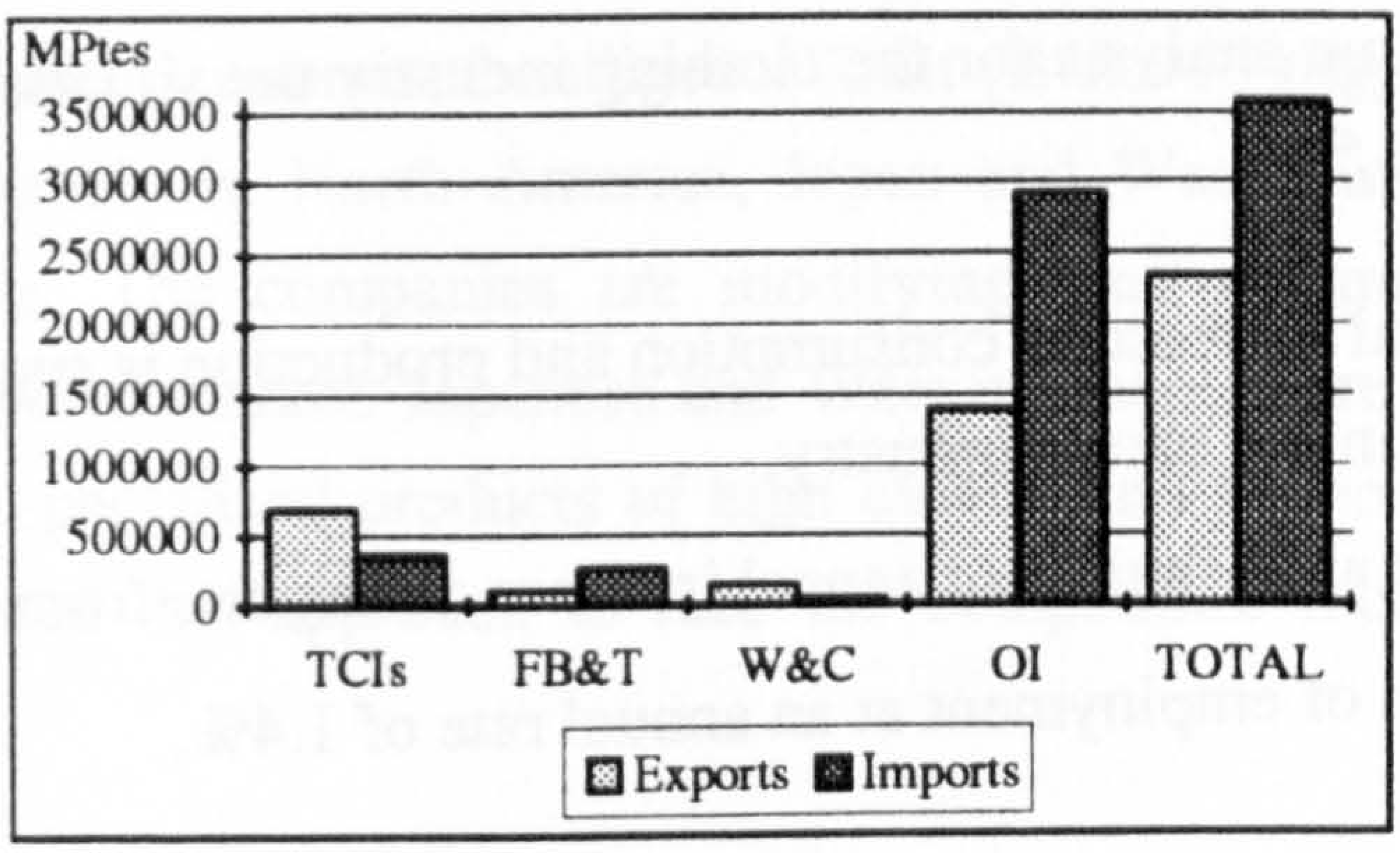

Figure 68 - Exports and Imports(1)

This scenario shows that important improvements must be done to overcome the main problems of the industry. These problems suggest difficulties in technology and equipment, and mainly in structure, organisation and management.

1.5. The TCIs and the EC

Table 50 shows some of the main indicators of the EC textile and clothing industries, between 1985 and 1988 [PIC90]. The analysis of the textile industry shows the following situation:

- Reduction of exports,
- The annual average increase of imports was superior than annual average increase of exports,
- Reduction of employment, at an annual rate of 1.7%,
- Stabilisation of the number of companies,
- High increase of investment.

Table 50 - Main indicators for the EC textile industry (millions of ECUs)

	1985	%	1986	%	1987	%	1988	%	AGMR
Consumption	77725	98.3	80189	98.9	82290	100.2	85058	100.9	3.05
Production	79063	100.0	81058	100.0	82131	100.0	84300	100.0	2.16
Exports	12688	16.0	12499	15.4	13309	16.2	13856	16.4	2.98
Imports	12565	15.9	11630	14.3	13460	16.4	14614	17.3	5.16
Employment (thousands)	1630		1603		1578		1548		-1.72
No. of companies	77512		78164		78380		78307		0.34
Investment	3388		3842		4045		4125		6.78

Regarding the same analysis for the clothing industry the situation can be summarised as follows (Table 51):

- The annual increase of consumption and production is superior to those observed in the textile industry,
- Important and significant annual increase of imports from outside EC,
- Reduction of employment at an annual rate of 1.4%,

Table 51 - Main indicators for the EC clothing industry (millions of ECUs)

	1985	%	1986	%	1987	%	1988	%	AGMR
Consumption	43909	104.9	45440	106.2	47677	109.7	51712	111.2	5.60
Production	41844	100.0	42771	100.0	43471	100.0	46514	100.0	3.59
Exports	4736	11.3	5007	11.7	5033	11.6	5089	10.9	2.43
Imports	7648	18.3	7844	18.3	9432	21.7	10394	22.3	10.77
Employment (thousands)	1095		1097		1069		1051		-1.36

In what concerns the evolution of the TCIs in the EC, the employment situation in 1987 for each EC country was the following (Table 52):

Table 52 - TCIs employment per country as a percentage of total EC employment

	Employment (%)		Employment (%)
Portugal	6.7	Spain	12.0
Italy	23.5	Greece	4.1
United Kingdom	16.8	Belgium	3.5
Germany	15.1	Remainder	1.0
France	14.9		

Between 1960 and 1989, EC textile and clothing imports varied from 900 million ECUs to 40000 million ECUs. This means an annual rate of increase of 14%. In the same period, EC textile and clothing exports varied from 1800 to 21400 million of ECUs, which means an annual rate of increase of 9%. In this period Portuguese textile and clothing imports increased at an annual rate of 18.4% and exports increased at an annual rate of 21.6%.

1.6. The TCIs and the world market

A study leaded by the Economist Intelligence Unit [BOL91] suggests that the world textile industry, namely in North America, Japan and West Europe are crossing a consolidation phase. The companies are modifying their organisation to compete effectively in the world market. Japanese and West companies are being integrated in specific sectors of specialised products of high quality and service standards. Textile companies have used this approach to face the competition increase in the global market.

The characteristics of the most developed economies are: better production of high value added quality products; product diversification towards a greater variety of options and styles to meet customers expectations; utilisation of small and flexible production units. The investment in automation, namely in spinning and weaving, resulted in a minimisation of traditional problems related with industries based on intensive manpower. This fact allowed new opportunities to approach the textile industry as a global activity. Currently, the industry is much less dependent on the manpower. However, the level of automation is not yet as much developed as in other industries. Table 53 shows the textiles and clothing exports and imports for the main producers.

Table 53 - Major export and import countries

	Exports (%)		Imports (%)
Hong Kong	10.1	United States	17.7
Italy	10.1	Germany	13.6
Germany	9.1	France	6.9
South Korea	7.0	Hong Kong	6.6
China	5.9	United Kingdom	6.3
Taiwan	5.6		
France	4.5		

1.7. Actual problems and solutions

The textile industry is crossing one of the worst crises in the last decades. It is estimated that many EC companies will not survive in the near future [ANS90]. This situation is a consequence of low prices of products supplied by developing countries. But it is also a consequence of an absence of investment in organisation and innovation in management. The problem of the textile restructuration is also a question of innovation from infrastructures and commercial structures to company strategic practices. The industry has to compete through better productivity, reduced costs, and quality development factors. The price is no longer the main marketing argument. Other competitive dynamic factors are sometimes more important - namely better quality, greater variety, new design and taking into account the voice of the customer.

Another important factor is the up-grading of the business processes. It is related with data organisation (and the capacity to use that data as a systematic tool to allow the development of adequate strategies), and with training organisation (to promote a better management capacity in terms of marketing and logistics).

In the clothing industry technology and automation is not so well advanced as in the textile industry. The substitution of manpower is more difficult. Consequently, the approach is to increase product quality, and high value added products, to be competitive in non-price based factors.

1.8. The role of the National industrial policy

Twelve countries and over 300 million consumers are involved in the European Community (EC) market integration. This is much larger than the US market. The reduction of trade barriers within the EC market will help to make consumer needs more uniform, a tendency which already exists on a global scale. There is a growing tendency towards a global market in different industries. This situation has led governments to encourage efforts to increase Europe competitiveness and productivity. In Portugal the Ministry of Industry set up a strategic programme (PEDIP) to develop industry in terms of productivity and quality. Figure 69 shows the Portuguese national industrial policy. It is directed to promote the dynamic factors of competitiveness.

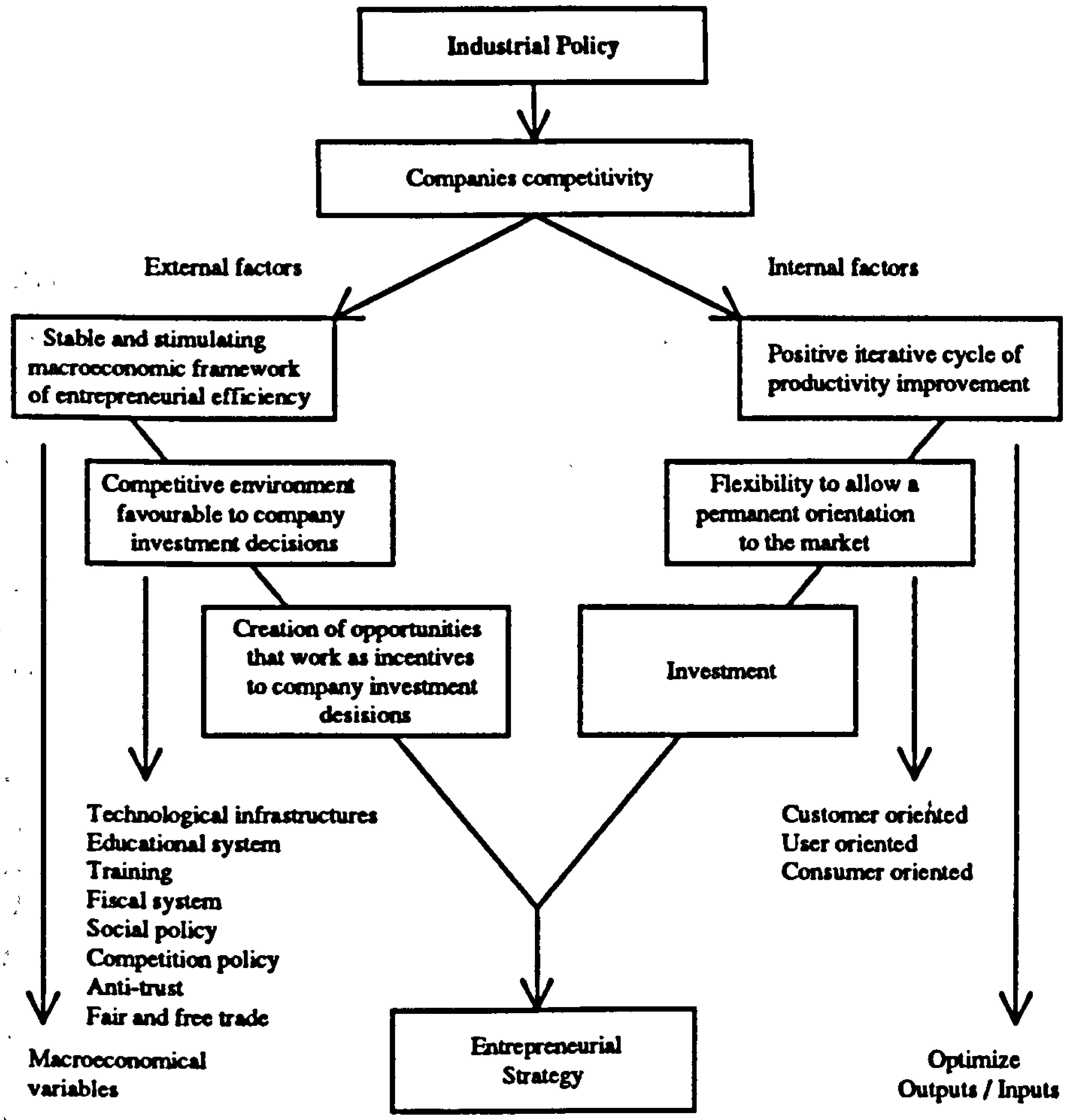

Figure 69 - The National industrial policy

The PEDIP supports actions of demonstration of new technologies and production techniques in industrial companies. The programme does not provide financial aid to buy production equipment. It only supports investments that lead to effective and proven increases in productivity, or quality or other relevant intangible factors. Actions of demonstration are projects of implementation of innovative ideas. Some examples include CIM, robotics and automation, JIT, TQM, AMT, and DFM projects. These projects must be shown to the community and other companies are invited to visit the demonstrator company.

This industrial policy can promote the introduction of Lean Manufacturing in the textile industry.

2. Annex - Diagnosis Questionnaire

1. Company

Name:
Address:
Contact:

	YES	NO	If yes (%)
Private			
Public capital			
Foreign capital			

2. Activity

	YES	Comments
Wool		
Cotton		
Knitting		
Non-woven		
Dyeing/finishing		
Stamping		
Clothing		
Others		

3. Market

	%	Comments
National		
Exportation		
Total number of clients		

4. Turnover (millions of escudos)

	Value	Comments
Less than 50		
50 to 100		
100 to 300		
300 to 500		
500 to 1000		
More than 1000		

5. Personnel

	N.	Comments
Production		
Engineering		
Quality		
Production control		
Finance		
Marketing		
Purchasing		
Maintenance		
Warehousing		
Others		
TOTAL		

6. Basic education

	University	High school	Secondary school	Lower
Production Mng.				
Technical services Mng.				
Quality Mng.				
Purchasing Mng.				
Supervisors				
Comments:				

7. Social and labour relationships

		Comments
Excellent		
Good		
Reasonable		
Fair		

8. Technology available

	YES	Comments
Office automation		
Computerised PP&C		
CNC machines		
CAD		
CAM		
Others		

Average age of machines

	All machines	Most machines	Few machines
Less than 5 years			
5 to 10 years			
More than 10 years			

Utilisation of installed production capacity: ______%

9. Main obstacles and difficulties (1 - Not important 4 - Very important)

	Imp.	Comments
Financial capacity		
Knowledge of markets		
Selling prices		
Response to orders in time		

10. Limitative factors of success (1 - Not important 4 - Very important)

	Imp.	Comments
Employees attitudes		
Training		
Old technology		
Strikes		
Lost of markets		
External economic factors		
Non-quality costs		
Raw-material costs		
Laws		
International competition		

11. Means to improve productivity (1 - Not important 4 - Very important)

	Imp.	Comments
Planning and organisation		
Computer systems		
Quality		
Laws		
Training		
Automation		

12. Means to reduce costs (1 - Not important 4 - Very important)

	Imp.	Comments
Motivation		
Quality		
Technology		
Product design		
Production processes		
Training		
Stock control		
Supplier selection		

13. Ranking by importance (1 - More important 4 - Less important)

	Imp.	Comments
Quality		
Costs		
Planning/organisation		
Profit		

14. Means to improve quality (1 - Not important 4 - Very important)

	Imp.	Comments
Training		
Process control		
Equipment/technology		
Experts/engineers		
Employees control		
Suppliers control		
Product follow-up		

15. Ranking people by importance (1 - More important 4 - Less important)

	Imp.	Comments
Top management		
Managers		
Supervisors		
Workers		

16. Customer requirements

	YES	Comments
Delivery dates		
Quality control equipment		
Production equipment		
Quality assurance (if YES, which standards)		
None		

17. Indicators for product quality

	YES	Comments
Comparison with competitors		
Customer complaints		
Quality Control reports		
Customer opinions		
Turnover		
Quality costs		
Quality audits		
Others		
None		

18. Means of control of supplies

	YES	Comments
Visual inspection		
Internal lab.		
External lab.		
None		

Type of control:		Comments
100%		
Sampling		
Randomly		

19. Non-quality costs

	YES	Value (as a percentage of turnover)
Are non-quality costs evaluated?		
Are non-quality costs estimated?		

20. Solving quality problems

	YES	Comments
Nowhere		
Suppliers		
Customers		
Other companies		
Technical associations		
Universities		
Consultants		
Others		

21. Quality organisation

	YES	Comments
Quality manual		
Calibration of test equipment		
Inspection of raw materials		
SPC		
Standardisation		

22. Specific quality training

	Internal	External	None	Comments
Quality control Mng.				
Inspectors				
Analysts				
Others				

3. Annex - Company audit checklists

1. Company

Name:
Address:
Contact:

2. Product

Type of products
Number of different products
Number of options
Number of new products introduced per year
Conception mean time of a new product
Mean time to market of a new product
Collections per year
Customers size (large, small, variable)

3. Production

Type of production: Large batches / Small batches / One of a kind / Continuous
Production capacity (in units/weigh/volume)
Production lead time per product (process time + inspection time + wait time + move time)
Cycle time
Manufacturing cycle efficiency (process time/production lead time)
P:D ratio (production lead time of a product/delivery lead time to customers)
Machine minutes per part
Throughput efficiency - processing time/throughput time
Waste time (in terms of production capacity) - Days/year
Set up times
Number of setups
Average setup time - total setup hours/no. of complete setups
Up time
% setup time to production lead time
Unscheduled machine downtime
% unscheduled machine downtime to production lead time
Time to introduce new products
Number of alterations introduced after the production have started

4. Production costs

Raw material in warehouse
Finish products in ware house
Work-in-process
Value added
Overheads
Production unit costs Material unit costs Overhead unit costs

5. Innovation

Design cycle time
Lead time of new product introduction (from design to first sale)
Number of new products launched
Investment in new products and processes
Key characteristics of new products relative to those of competitors (obtained from customer survey)

6. Quality

Incoming quality
% defects of incoming materials
Frequency purchases returns
Number of suppliers
In-house quality
% scrap
% rework
Number of defects
Time between defect detection and correction
% first-pass without rework
Reject rate of finished products
Internal failure costs
Outgoing quality
Number of customer complaints
Number of warranty claims
Cost of warranty claims
% surveyed customers who are satisfied
% repeat sales to existing customers
External failure costs

7. Delivery

Incoming delivery:
Purchasing lead time
% supplier's on time delivery
% supplier's early delivery
% supplier's late delivery
Outgoing delivery:
Number of deliveries
% engineering change orders
Number of production schedule changes
Number of past due orders
Total number of orders
% on time delivery to customers
% early delivery to customers
% late delivery to customers
Average lateness of delivery
Delivery lead time to customers

6. Equipment

1 - Inadequate. 5 - Adequate	1	2	3	4	5
No. of machines					
No. of CNC machines					
No. of machines with CAM					
Equipment performance					
Equipment obsolescence (average age)					
Level of quality expected					
Lab. equipment					
Test equipment					
Working space					
Space for circulation					
Materials handling equipment					

7. Robotics/automation

1 - Inadequate. 5 - Adequate	1	2	3	4	5
Production equipment					
Test equipment					
Materials handling equipment					
% of automated equipment to conventional					

8. Materials handling

1 - Inadequate. 5 - Adequate	1	2	3	4	5
Conveyors					
AGVs					
Robots					
Air transporters					
Computer controlled conveyors					
Materials handling time					
% materials handling time to production lead time					

9. Warehousing

1 - Inadequate. 5 - Adequate	1	2	3	4	5
Ratio of warehousing space to manufacturing space					
Raw materials residence in warehousing					
Finished products residence in warehousing					
Space available					
Space for circulation					
Packaging and expedition area					

10. Integration technologies - CIM

1 - Inadequate. 5 - Adequate	1	2	3	4	5
Computer systems					
Networks LANs WANs					
CAD					
CAM					
CIM					
PP&C systems					
Shop floor terminals					
Warehouse terminals					
Accounting and finance					
Administration					

11. Layout

1 - Inadequate. 5 - Adequate	1	2	3	4	5
Production					
Warehouses					
Administration					
Global					
Ratio of manufacturing space to total space					
Distance travelled by products					

12. Production planning and control

1 - Inadequate. 5 - Adequate	1	2	3	4	5
Just-in-time					
Group technology					
MRP • Simulation of work centre loads • Sharing demand patterns and lead time with vendors • Computer-generated work centre priorities • Computer-based tracking of inventories					
Adherence to scheduling					
Line balancing					
Production in cells					
Management by eye					

13. Inventory management

1 - Inadequate. 5 - Adequate	1	2	3	4	5
Inventory levels					
Inventory turnover					
Number of days of stock					
Out-of-stock rate					
Bar coding identification					
Work-in-process ____ % ____ $					
Raw material in warehouse ____ % ____ $					
Finish product in warehouse ____ % ____ $					
Stock rotation per year					

14. Work study

1 - Inadequate. 5 - Adequate	1	2	3	4	5
Job design					
Job rotation					
Job descriptions					
Ergonomic study					
Team work					
Time measurement					
MTM					

15. Maintenance management

1 - Inadequate, 5 - Adequate	1	2	3	4	5
Equipment capacity/utilisation					
Availability/downtime					
Machine maintenance					
Mean time between failures					
Mean time to repair					
Predictive maintenance					

16. Environmental conditions

1 - Inadequate. 5 - Adequate	1	2	3	4	5
Lighting					
Noise					
Smells					
Vibrations					
Ergonomics of work place					

17. Main problems

1 - Not important, 5 - Very important	1	2	3	4	5
Produce with high quality standards					
Introduce new products					
High overhead costs					
Low productivity of direct work					
Low productivity of indirect work					
Defects and rejections rate					
Weak forecast of demand					
Excess of production capacity					
High cost of raw materials					
Constant evolution of technology					

18. Company strategy (for the next five years)

1 - Not important, 5 - Very important	1	2	3	4	5
Long term strategy (written) to guide manufacturing					
Develop of new products for actual market					
Increase market share					
Develop new products for new markets					
Enter in new markets with old products					
To grow (by acquisitions, fusion, etc.)					
To retire from certain markets					
Integrate information systems					

19. Main focused programmes

1 - Not important. 5 - Very important	1	2	3	4	5
Stock control					
Production management					
Reduction of man power					
Motivation of direct personnel					
Motivation of indirect personnel					
Training: Managers Supervisors Workers					
Development of new processes for old products					
Development of new processes for new products					
Safety					
Integration of information systems					
Production reorganisation					
Quality circles					
CAD					
CAM					
CIM					
Automation					
Office automation					

20. Competitive priorities

1 - Not important. 5 - Very important	1	2	3	4	5
Consistent quality					
High performance of products					
Delayed deliveries					
Low prices					
Fast design changes					
Fast introduction of new products					
Fast deliveries					
After-sales service					
Fast changes in volumes (quantities)					

21. Financial indicators

	Value	Comments
Company growth in the last 3 years (sales - raw materials)		
Manpower		
Cost of manpower		
Capital		
Conversion/flexibility		
Profitability		
Stock rotation		
Working capital		

4. Annex - Checklist for assessment of Quality Systems

1. Organisation for Quality

1.1 Quality function	YES	NO
Quality function or Quality Department		
Quality manager		
Name:		
Sex:		
Age:		
No. of years as quality manager:		
No. of years in the quality function:		
Previous functions:		
No. of years in previous functions:		
Academic background:		
Professional background:		
Professional institute or association:		
Quality manager functions:		
Only in the quality area		
Shares other functions (ex: managing director)		
Depends on the managing director		
Depends on the board of directors		
Depends on the		
Documented organisational chart		
Defined responsibilities and duties for each function		
Ambiguity of authority in some functions		
Superposition of responsibilities in some functions		
"Direct line" between Quality and Production managers		

1.2 Quality Personnel	YES	NO
Inspectors:		
Analysts:		
Job descriptions/working instructions		
Written		
Not written		
Formal training:		
periodically		
not periodically		
No. of in-house training courses:		
No. of people involved:		
Average length of training:		
No. of external courses:		
No. of people involved:		
Average length of training:		
Training is left to "on the job experience"		
Verbal training is given		
No methods at all		

1.3 Production personnel	YES	NO
Job descriptions/working instructions		
Written		
Not written		
Formal training:		
periodically		
not periodically		
No. of in-house training courses:		
No. of people involved:		
Average length of training:		
No. of external courses:		
No. of people involved:		
Average length of training:		
Training is left to "on the job experience"		
Verbal training is given		
No methods at all		

1.4 Training	YES	NO
General awareness quality training		
Problem solving, quality tools		
SPC		
Inspection and lab techniques		
Standardisation and certification		
Internal auditing		
Most qualified worker:		
Familiar with SPC		
Good knowledge of QC techniques		
Some knowledge of QC techniques		
Some knowledge of specifications and metrology but little of QC techniques		
Only some knowledge of specifications and metrology		

1.5 Top management	YES	NO
Total commitment to Quality		
Recognise the need to spend more attention and in a systematic way to Quality		
Feeling that it should be given more priority to Quality		
Casual interest for Quality		
Indifference		

1.6 Motivation incentives for Quality	YES	NO
Posters and charts		
Rewards and prizes for quality improvement suggestions		
Rewards for introduced improvements		
Formal plan for career development		

1.7 Quality tools	YES	NO
Pareto analysis		
Brainstorming techniques		
Ishikawa/fishbone diagrams		
Histograms and charts		
Quality circles, improvement teams		
Focused programmes		
Taguchi methods		
Failure mode and effect analysis (FMEA)		
Quality function deployment (QFD)		
Fault tolerance analysis (FTA)		

2. Quality System

2.1 Quality policy	YES	NO
Written quality policy		
Known in all levels of the organisation		

2.2 Awareness and involvement for QS	High	Low	Indifferent
CEO			
Upper management			
Middle management			
Supervisors			
Workers			

2.3 Motivation for the implementation of QS	High	Low	Indifferent
Customers pressure			
Market pressure			
Scrap reduction/Cost reduction			
Other reasons:			
None			

2.4 Quality Manual	YES	NO
Written quality manual		
Completed		
Implemented		
Known in all levels of the organisation		

2.5 Procedures	Good	Adequate	Fair/ None
Management responsibility			
Quality system principles			
Internal auditing			
Quality-related costs			
Contract review			
Design control			
Purchasing			
Process control			
Control of production			
Product identification and traceability			
Inspection and test status			
Inspection and testing			
Inspection, measuring and test equipment			
Control of non-conforming product			
Corrective actions			
Handling, storage, packaging and delivery			
After-sales servicing			
Document control			
Quality records			
Training			
Product safety and liability			
Statistical techniques			
Purchaser supplied product			
None			

2.6 Specifications and instructions	Good	Adequate	Fair/ None
Finished products:			
all			
some			
Raw material (and bought out goods):			
all			
some			
Purchasing			
Testing:			
all			
some			
Subcontracting			
Contract review			
Design and development of new products			
Packing and delivery			
None			

2.7 Focused programmes	YES	NO
Raw-materials control Suppliers control Suppliers qualification Process control Product control Evaluation of quality related costs Quality system certification Problem solving techniques		
None		

2.8 Quality system certification	YES	NO
The company is certificate The company applied for the certification The company is not interested in certification The company knows the meaning of certification The company knows the ISO9000 The company knows the EN29000		

2.9 Internal quality audits	YES	NO
In a systematic basis Periodicity: Quality auditing plan Written instructions (and checklists) Audit records Audit reports		
External quality audits By customers By third parties Reports are used to improve the quality system		

2.10 Corrective actions	YES	NO
Written corrective actions procedures for rejected materials or other quality problems Records assure that product met specifications Easy and fast access to records The system computerised Records are maintained for a specified period		

2.11 Inspection, measuring and test equipment	YES	NO
The measuring and test equipment is adequate The measuring and test equipment is maintained The measuring and test equipment is calibrated Calibration plan Written calibration procedures		

2.12 Measuring quality	YES	NO
Waste		
Lost and defects		
Customer complaints		
Late deliveries		
Quality costs		
Others:		
None		

3. Quality Control

3.1 Statistical quality control	"normal"	SPC	Since
Reception - purchased materials			
Processes			
Finished products			
All stages			
SPC is a customer requirement	YES		NO

3.2 No use of SPC	YES	NO
No knowledge of SPC techniques		
Not aware of SPC benefits		
Aware but never tried		
SPC was tried but without benefits		
SPC is being implemented		

3.3 Reception control	YES	NO
Sampling		
100 %		
Randomly		
Data from reception control is used to draw a record of supplier performance		
Raw-material conformity certificates are demanded		

3.4 Control charts	Knowledge			Use		
	None	Slight	Subs-tantial	None	Slight	Subs-tantial
Mean and range charts						
np charts						
p charts						
Cusum charts						
Moving mean and range charts						

3.5 Sampling techniques	Knowledge			Use		
	None	Slight	Subs-tantial	None	Slight	Subs-tantial
Acceptance sampling:						
Simple sampling						
Double sampling						
Multiple sampling						
Sampling schemes:						
Attributes						
Variables						

3.6 Non-conformities	YES	NO
Identification with special tags		
Identification in the operation sheet		
Segregation in a specific area		
No method		

3.7 Process control	YES	NO
Auto-control		
Sampling		
Randomly		
Computerised testing equipment		
Process capacity studies		
Other methods		
None		

3.8 Final product control	YES	NO
Sampling		
100 %		
Randomly		
Data is recorded		
Product durability and reliability is monitored		
This information helps to modify/develop/improve:		
the product		
new specifications for purchasing		

3.9 Complaints follow-up	YES	NO
Substitution of non-conform product		
Devolution of money		
Other:		
Average no. of complains per year:		
Data is recorded		

3.10 Customer satisfaction evaluation	YES	NO
Use of questionnaires		
Complaints analysis		
Rejections/warranties		

4. Quality-related Costs

4.1 Evaluation of quality-related costs	YES	NO
Quality costs are evaluated		
Value:		
Quality costs are estimated		
Value:		
Non-quality costs are evaluated		
Value:		
Non-quality costs are estimated		
Value:		

4.2 Evaluation criteria	YES	NO
Prevention costs		
Quality engineering		
Quality planning		
Training		
Process control		
Quality audits		
Improvement projects		
Appraisal costs		
Receiving inspection		
WIP inspection		
Final inspection		
Test equipment calibration		
Dispositioning		
Quality reporting		
Internal failure		
Defects		
Rework		
External failure		
Complaints		

4.3 Areas involved in quality cost evaluation	YES	NO
Product design and development		
Marketing		
Purchasing		
Finance and administration		
Manufacturing		
Customer service		

5. Annex - Checklist for assessment of Flexibility

1. Component characteristics

1 - Decreased a lot, 5 - Increased a lot	1	2	3	4	5
• Number of different components manufactured at any one time • Total number of different parts used • Number of common parts per product • Range of difference in the components • Percentage of standard components • Percentage of common components • Annual production volume of a component • Lot size of a component • Complexity of a component design • Degree to which components are modified to meet customer requirements • Tolerances used in manufacturing components					

2. Component design and new components

1 - Decreased a lot, 5 - Increased a lot	1	2	3	4	5
• Frequency of manufacture of new components • Frequency of major design changes in existing components • Frequency of minor design changes in existing components • Frequency of manufacture of new component introductions relative to design changes in existing components					
• Time needed to adapt the production process to a new component • Time needed to adapt the production process to a major design change • Time needed to adapt the production process to a minor design change					
• Constrains exercised by the production equipment on the design of a new component • Constrains exercised by the production equipment on a major design change in an existing component • Constrains exercised by the production equipment on a minor design change in an existing component					

3. Characteristics of the production process

1 - Decreased a lot, 5 - Increased a lot	1	2	3	4	5
• Total number of different processes used					
• Automation of material handling between machines					
• Grouping of production operations into single machines					
• Interdependence between a work station and the preceding and following work stations					
• Ability to predict daily production volumes					
• Levels of in-process inventory					
• Amount of time that those managers responsible for production devote to problem with the production process					
• Ease in change production volume for a component					
• Ease in changing the lot size of a given component					
• Ease in changing the number of different components being manufactured over time					
• Ease in changing the organisation of work					
• Ease in rerouting components when a machine breakdown occurs					
• Ease in making design changes in existing components					
• Ease in changing the output rate					
• Amount of time devoted to setting up for the next lot					
• Degree of mechanisation of quality control operations					
• Degree to which an equipment improvement in one spot affects an integrated system of different machines					
• How often during a typical month occurs a break into scheduled production for a special order					
• Output rate					
• Ability to adhere to tolerances					
• % of engineering change orders					
• No. of different processes					
• No. of levels in the bills of materials					

4. Production capacity

1 - Decreased a lot, 5 - Increased a lot	1	2	3	4	5
• Ability to accurately estimate the capacity limits of the equipment					
• Ability to vary capacity limits					
• Number of multi purpose equipment					
• Average volume fluctuations that occur over a given period of time					

5. Material inputs

1 - Decreased a lot, 5 - Increased a lot	1	2	3	4	5
• Number of different kinds of materials used in a component					
• Number of different sources of material inputs for a component					
• Fraction of suppliers outside the company with whom there are contracts lasting for a year or more					
• Fraction of material inputs (in £) supplied by single sources					
• Proportion of material inputs (in £) from inside the company as opposed to outside the company					
• Level of material input inventories (in £)					
• Frequency at which material input orders are placed					
• Amount of an order for material inputs (in £)					
• Tolerances defining the quality of material inputs					

6. Organisation of work

1 - Decreased a lot, 5 - Increased a lot	1	2	3	4	5
• Skill level of operators					
• Range of skills used by an operator					
• Qualification level of operators in terms of diplomas or certificates					
• Amount of inside company training for operators					
• Amount of outside company training for operators					
• Amount of pay for operators					
• Amount of time it takes to perform a complete cycle of the task of an operator					
• Degree of discretion operators have over the execution of their work					
• Degree of discretion operators have over the planning of their work					
• Degree of discretion operators have over their work pace					
• Amount of maintenance activities performed by operators					
• Amount of inspection activities performed by operators					
• Amount of computer programming activities performed by operators					
• Amount of tool setting activities performed by operators					
• Degree to which operators do the same tasks in the same way everyday (repetition of tasks)					
• Degree to which operators' tasks are well defined and structured					
• Amount of direct vs. indirect labour performed					
• Total no. of tasks in the manufacturing process					
• Average no. of tasks performed by each operator					

6. Annex - Checklist for assessment of Anthropocentric issues

1. Resources plan

1 - Inadequate, 5 - Adequate	1	2	3	4	5
Does the human resources plan support the quality plan objectives and strategies?					
• Does it include individuals at all levels? • Is it integrated with the quality plan?					

2. Strategy for employee involvement

1 - Inadequate, 5 - Adequate	1	2	3	4	5
Does the resources plan identify strategies to increase individual involvement and effectiveness in the quality process?					
• Training and education • Teams (internal/external, union/mgt.) • Employee feedback process (forums) • Increasing individual responsibilities					
Are all employees involved (participating in the quality involvement process)?					
• Suggestion programme • Technology transfer • Supplier/customer relationships • Disposition of non conformance • Problem solving teams • Other empowerment and feedback programmes					

3. Recognition

1 - Inadequate, 5 - Adequate	1	2	3	4	5
Is quality performance measured and are individuals recognised for their contributions?					
• Performance reviews • Newsletter articles • Attendance records • Quality awards					

4. Training

1 - Inadequate, 5 - Adequate	1	2	3	4	5
Is there an active training programme?					
Is there a system for identifying training needs and methods for providing the proper education, knowledge and skills (all levels)?					
Topics covered: • Understanding quality management • Statistical techniques • Statistical sampling • Data collection and analysis • Problem solving • Communications and group skills • Auditing • Job knowledge and skills • New employee orientation					
Methods: • Classroom • Electronic (video, audio cassette, interactive computer-based) • Publications, newsletters, employee handbooks, programmed instructions					

5. Qualification programme

1 - Inadequate, 5 - Adequate	1	2	3	4	5
Is there a certification, qualification programme to determine competency for individuals performing special tasks?					

6. Health and safety

1 - Inadequate, 5 - Adequate	1	2	3	4	5
Does the organisation address quality-of-life issues as part of the quality process (employee well-being and morale?					
• Safety, work environment improvements • Health promotion • Recreational/activity teams/clubs • Employee volunteer programme • Employee feedback system					

7. Social environment

1 - Inadequate, 5 - Adequate	1	2	3	4	5
• Relationships between managers • Relationships between managers and workers • Relationships between workers					
• Job rotation • Job satisfaction • Job enrichment • Job enlargement					
• Worker participation • Recognition • Quality circles • Qualifications • Absenteeism					

7. Annex - Analysis by company size

This annex complements section 5.1 - Results from the diagnosis questionnaire. It illustrates all the analysis from the company size view point.

Table 54 - Main obstacles/difficulties

	No. of employees	Lack of financial capacity				Insufficient knowledge of markets				Non competitive prices				Delivery in time			
		W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl
4	<50	6	7	5	7	2	5	2	2	4	3	7	8	3	-	4	-
	50 to 99	3	-	6	4	4	-	5	2	-	-	5	4	3	-	8	5
	100 to 199	4	5	-	7	2	-	2	-	2	3	4	6	2	2	6	2
	200 to 499	2	6	-	9	-	-	-	2	3	5	4	5	3	3	4	4
	500 to 999	9	6	-	-	-	-	-	-	3	2	3	-	2	-	-	2
	>1000	-	3	-	2	-	2	-	2	-	6	-	2	-	2	-	-
3	<50	4	6	8	7	-	5	8	3	2	9	2	2	2	2	6	10
	50 to 99	7	6	8	3	2	3	6	3	3	3	13	1	7	3	3	5
	100 to 199	5	5	3	5	2	-	3	3	3	6	2	6	5	-	2	3
	200 to 499	4	6	8	7	3	5	4	7	4	11	8	8	4	2	3	5
	500 to 999	-	-	-	-	2	-	-	-	4	6	-	2	4	2	2	-
	>1000	-	-	-	2	-	-	-	-	-	2	-	3	-	2	-	5
2	<50	-	2	5	2	4	5	5	10	2	6	9	2	3	3	6	5
	50 to 99	3	2	3	3	4	5	8	3	10	4	2	6	3	2	3	-
	100 to 199	2	-	3	5	3	3	4	10	5	-	3	6	1	6	-	7
	200 to 499	3	3	2	-	3	10	9	7	3	2	2	5	3	6	6	7
	500 to 999	3	2	2	2	5	6	2	-	5	-	-	-	3	-	1	-
	>1000	-	2	-	1	-	4	-	-	-	-	-	-	-	2	-	-
1	<50	-	3	3	2	4	3	6	3	2	-	3	6	2	13	5	3
	50 to 99	2	-	5	3	5	-	3	5	2	1	2	2	2	3	8	3
	100 to 199	2	1	3	1	6	8	-	5	3	2	-	-	5	3	1	6
	200 to 499	3	5	6	5	6	5	3	5	2	2	2	3	2	9	3	5
	500 to 999	-	-	1	-	5	2	1	2	-	-	-	-	3	6	-	-
	>1000	-	4	-	-	-	3	-	3	-	1	-	-	-	3	-	-

W - Wool; Co - Cotton; K - Knitting; Cl - Clothing
4 - Very important; 3 - Important; 2 - Less important; 1 - Not important

Table 55 - Obstacles to success

	No. of employees	Employees atitudes				Training				Technology obsolescence				Strikes			
		W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl
4	<50	2	3	-	-	2	3	7	-	2	3	2	2	-	1	-	-
	50 to 99	-	-	2	2	6	2	3	3	6	2	3	2	-	-	-	-
	100 to 199	-	-	-	5	5	2	2	8	6	3	-	3	-	-	1	3
	200 to 499	2	-	2	2	5	4	2	12	1	2	-	-	-	1	-	2
	500 to 999	2	1	-	-	3	-	-	1	-	-	-	-	1	-	-	-
	>1000	-	1	-	-	-	2	-	2	-	-	-	-	-	1	-	-
3	<50	-	2	5	2	6	10	8	8	6	5	3	-	-	2	-	-
	50 to 99	3	-	6	3	9	3	13	5	3	-	8	3	-	-	1	-
	100 to 199	-	2	6	3	6	6	3	7	5	2	5	3	-	-	-	-
	200 to 499	4	2	2	5	3	13	6	7	1	7	3	2	-	2	-	2
	500 to 999	6	1	2	-	6	5	2	-	3	3	3	-	-	-	-	-
	>1000	-	2	-	-	-	5	-	2	-	2	-	-	-	2	-	-
2	<50	4	5	8	3	2	5	6	7	1	5	5	10	-	2	4	-
	50 to 99	7	2	8	3	-	-	6	3	4	3	6	3	-	2	2	3
	100 to 199	7	2	-	5	-	2	3	3	1	1	2	3	-	-	-	2
	200 to 499	4	5	4	7	4	3	8	2	3	5	3	8	-	2	2	4
	500 to 999	3	1	1	2	3	2	1	1	6	3	-	1	2	2	-	1
	>1000	-	4	-	3	-	-	-	1	-	2	-	2	-	-	-	2
1	<50	4	8	8	13	-	-	-	3	1	5	11	6	10	13	17	18
	50 to 99	5	6	6	5	-	3	-	2	2	3	5	5	15	6	19	10
	100 to 199	6	7	3	5	2	1	1	-	1	5	2	9	13	11	8	13
	200 to 499	2	13	8	7	-	-	-	-	7	6	10	11	12	15	14	13
	500 to 999	1	5	-	-	-	1	-	-	3	2	-	1	9	6	3	1
	>1000	-	2	-	2	-	2	-	-	-	5	-	3	-	6	-	3

	No. of employees	Market losses				External econo-mical factors				Non-quality costs				Price of raw-matrials			
		W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl
4	<50	2	2	3	2	4	6	6	7	3	3	4	5	2	3	6	8
	50 to 99	-	-	2	2	2	6	5	3	1	-	-	-	-	-	10	3
	100 to 199	-	2	2	3	-	2	2	7	1	2	5	3	2	5	2	6
	200 to 499	-	3	-	3	-	2	3	5	2	2	3	9	-	2	3	3
	500 to 999	2	-	-	-	3	2	-	-	2	-	2	1	-	-	-	-
	>1000	-	-	-	-	-	5	-	3	-	1	-	3	-	2	-	3
3	<50	2	4	5	6	3	10	6	8	3	3	5	2	3	10	5	5
	50 to 99	1	1	5	3	10	2	11	5	10	3	6	5	2	5	6	5
	100 to 199	1	2	2	4	4	2	5	6	6	1	2	4	3	2	4	8
	200 to 499	2	5	10	4	8	10	8	9	4	15	5	7	2	11	10	9
	500 to 999	1	3	-	1	7	3	-	1	6	2	1	-	4	4	3	1
	>1000	-	2	-	3	-	2	-	2	-	-	-	2	-	-	-	-
2	<50	4	6	8	5	1	2	6	3	2	6	6	8	3	3	10	5
	50 to 99	6	2	9	6	3	-	6	2	4	5	11	5	11	1	6	3
	100 to 199	5	1	-	5	2	-	1	5	4	5	-	8	5	2	1	2
	200 to 499	6	5	-	9	2	5	-	7	6	3	6	3	7	6	3	7
	500 to 999	3	2	-	1	2	3	1	1	4	4	-	-	8	2	-	1
	>1000	-	2	-	2	-	2	-	-	-	5	-	-	-	5	-	2
1	<50	2	6	5	5	2	-	3	-	2	6	6	3	2	2	-	-
	50 to 99	8	5	6	2	-	-	-	3	-	-	5	3	2	2	-	2
	100 to 199	7	6	5	6	7	7	1	-	2	3	2	3	3	2	2	2
	200 to 499	4	7	6	5	2	3	5	-	-	-	2	2	3	1	-	2
	500 to 999	6	3	3	-	-	-	2	-	-	2	-	1	-	2	-	-
	>1000	-	5	-	-	-	-	-	-	-	3	-	-	-	2	-	-

	No. of employees	Legislation				Competition of low labour countries			
		W	Co	K	Cl	W	Co	K	Cl
4	<50	-	3	2	8	4	11	13	12
	50 to 99	2	-	2	5	4	6	14	6
	100 to 199	2	-	3	6	4	8	8	6
	200 to 499	-	-	2	11	3	13	8	15
	500 to 999	3	3	-	-	4	6	1	-
	>1000	-	3	-	2	-	6	-	2
3	<50	3	5	8	1	3	5	3	2
	50 to 99	7	2	9	4	6	2	5	3
	100 to 199	4	2	-	1	7	2	-	7
	200 to 499	4	8	3	2	4	5	8	1
	500 to 999	4	3	1	1	6	2	2	-
	>1000	-	1	-	2	-	3	-	3
2	<50	3	2	9	6	-	2	-	2
	50 to 99	6	3	8	2	3	-	2	3
	100 to 199	4	4	6	6	-	1	1	3
	200 to 499	2	4	6	6	2	2	-	3
	500 to 999	5	2	2	1	2	-	-	2
	>1000	-	5	-	1	-	-	-	-
1	<50	4	8	2	3	3	-	5	2
	50 to 99	-	3	3	2	2	-	1	1
	100 to 199	3	5	-	5	2	-	-	2
	200 to 499	6	8	5	2	3	-	-	2
	500 to 999	-	-	-	-	-	-	-	-
	>1000	-	-	-	-	-	-	-	-

W - Wool; Co - Cotton; K - Knitting; Cl - Clothing
4 - Very important; 3 - Important; 2 - Less important; 1 - Not important

Table 56 - Means to improve productivity by company size

	No. of employees	Planning & Organisation				Computeri-sation				Quality				Labour laws				Training				Automation & technology			
		W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl
4	<50	1	10	10	8	-	2	5	7	5	6	9	8	1	3	2	3	4	5	10	8	4	6	8	3
	50 to 99	3	3	11	5	1	2	8	5	7	5	14	7	2	-	6	3	8	5	11	3	9	3	8	3
	100 to 199	4	3	8	15	1	5	5	7	4	3	5	10	3	-	2	3	8	3	5	8	4	9	3	3
	200 to 499	7	8	10	16	1	3	6	7	6	13	8	16	3	2	3	8	3	10	8	8	8	9	5	3
	500 to 999	7	-	3	2	-	-	-	-	2	3	2	-	3	2	-	-	5	2	-	-	9	6	-	-
	>1000	-	5	-	2	-	3	-	-	-	2	-	3	-	6	-	-	-	4	-	3	-	3	-	-
3	<50	6	3	3	7	4	7	9	6	3	8	6	7	3	5	5	8	4	8	10	5	3	10	5	8
	50 to 99	10	3	8	5	9	3	7	5	6	2	6	5	4	2	6	5	6	2	6	8	6	3	10	3
	100 to 199	5	2	1	2	8	2	2	6	6	8	3	7	1	6	3	5	4	3	3	8	9	2	4	11
	200 to 499	4	4	5	3	6	12	8	11	4	5	5	5	3	5	6	4	3	8	6	11	3	4	9	15
	500 to 999	4	5	-	-	9	3	3	-	7	5	1	-	4	4	1	2	6	6	2	-	3	2	3	-
	>1000	-	2	-	3	-	3	-	5	-	2	-	-	-	1	-	2	-	3	-	-	-	3	-	5
2	<50	3	5	3	3	3	6	5	5	1	2	3	2	1	3	6	5	2	2	1	5	3	2	5	7
	50 to 99	2	2	3	2	5	3	5	2	2	1	2	1	6	4	8	5	1	1	5	-	-	2	4	7
	100 to 199	1	2	-	1	4	2	-	5	2	-	-	-	5	-	3	7	1	5	1	2	-	-	2	4
	200 to 499	-	6	1	2	4	3	2	3	1	-	3	-	3	8	5	3	6	2	2	2	1	4	2	3
	500 to 999	1	2	-	-	2	3	-	2	3	-	-	2	3	2	2	-	1	-	1	2	-	-	-	2
	>1000	-	-	-	-	-	3	-	-	-	5	-	2	-	-	-	3	-	2	-	2	-	3	-	-
1	<50	-	-	5	-	3	3	2	-	1	2	3	1	5	7	8	2	-	3	-	-	-	-	3	-
	50 to 99	-	-	-	1	-	-	2	1	-	-	-	-	3	2	2	-	-	-	-	2	-	-	-	-
	100 to 199	3	4	-	-	-	2	2	-	1	-	1	1	4	5	1	3	-	-	-	-	-	-	-	-
	200 to 499	1	1	-	-	1	2	-	-	1	2	-	-	3	5	2	6	-	-	-	-	-	3	-	-
	500 to 999	-	2	-	-	1	2	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-
	>1000	-	2	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-

W - Wool; Co - Cotton; K - Knitting; Cl - Clothing
4 - Very important; 3 - Important; 2 - Less important; 1 - Not important

Table 57 - Relative importance of strategic items

	No. of employees	Quality				Costs				Due date				Profit			
		W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl
1st	<50	6	15	17	14	6	8	8	5	1	4	5	5	1	5	3	3
	50 to 99	10	5	10	8	-	6	8	-	7	5	8	3	3	1	10	3
	100 to 199	7	9	8	8	3	4	2	3	4	4	-	3	3	6	-	5
	200 to 499	7	12	6	11	2	6	6	3	3	5	2	3	4	1	8	5
	500 to 999	4	3	3	2	3	3	3	1	1	4	2	1	6	1	-	-
	>1000	-	5	-	3	-	1	-	3	-	1	-	2	-	5	-	-
2nd	<50	3	3	-	3	3	5	8	8	3	2	8	7	2	1	6	7
	50 to 99	3	2	3	5	8	1	6	3	3	1	8	5	4	1	2	2
	100 to 199	3	1	-	7	7	3	2	7	-	2	6	7	2	-	-	5
	200 to 499	1	4	8	3	6	7	3	6	3	6	6	8	3	5	-	3
	500 to 999	1	1	-	-	8	1	-	-	3	3	1	1	-	3	1	-
	>1000	-	3	-	2	-	5	-	-	-	2	-	1	-	2	-	2
3rd	<50	1	-	2	1	1	5	3	3	3	6	-	2	3	2	7	3
	50 to 99	-	1	6	-	7	1	3	7	5	1	4	3	-	1	2	1
	100 to 199	-	1	1	2	2	4	5	3	6	1	1	3	4	-	3	1
	200 to 499	-	1	-	2	3	7	5	9	6	2	5	5	1	6	3	2
	500 to 999	7	1	-	-	-	3	-	1	4	-	-	-	-	2	2	-
	>1000	-	1	-	-	-	2	-	2	-	1	-	2	-	2	-	-
4th	<50	-	-	2	-	-	-	2	2	3	6	8	4	4	10	5	5
	50 to 99	2	-	3	-	-	-	5	3	-	1	2	2	8	5	8	7
	100 to 199	3	-	-	1	1	-	-	5	3	4	2	5	4	5	6	7
	200 to 499	4	3	2	5	1	-	2	3	-	7	3	5	4	8	5	11
	500 to 999	-	3	-	-	1	1	-	-	4	1	-	-	6	2	-	2
	>1000	-	-	-	-	-	1	-	-	-	5	-	-	-	-	-	3

W - Wool; Co - Cotton; K - Knitting; Cl - Clothing

Table 58 - Means to reduce costs by sub-sector and company size

	No. of employees	Motivation				Quality				Technology				Design				Manufacturing processes				Training				Stock control				Suppliers			
		W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl
4	<50	-	3	8	-	5	3	11	3	6	8	11	8	2	2	4	5	5	6	3	10	5	7	7	5	1	6	3	7	-	2	5	5
	50 to 99	4	2	5	3	6	3	8	2	6	2	13	2	-	-	2	-	3	2	9	5	7	2	8	5	-	5	1	6	-	-	5	5
	100 to 199	7	5	3	7	5	3	5	10	6	6	4	7	2	3	5	3	3	5	8	8	5	3	5	8	2	3	7	9	-	-	3	5
	200 to 499	4	5	5	10	7	8	8	11	6	12	3	2	2	5	3	4	1	8	5	11	6	9	4	11	4	3	7	15	-	-	3	6
	500 to 999	-	3	-	-	5	5	2	-	7	5	2	-	-	-	-	-	4	2	-	-	2	2	-	-	5	-	3	2	1	-	-	2
	>1000	-	1	-	3	-	5	-	3	-	4	-	2	-	4	-	3	-	3	-	2	-	4	-	3	-	2	-	2	-	-	-	3
3	<50	7	10	5	7	3	8	5	8	3	6	6	7	4	3	11	8	4	8	9	3	4	8	9	10	3	5	9	3	3	9	3	8
	50 to 99	10	2	13	5	6	2	8	7	9	2	6	7	7	5	13	5	12	2	9	8	7	6	8	7	11	2	13	5	2	5	6	3
	100 to 199	5	3	6	7	7	5	3	5	7	5	5	8	4	6	4	7	7	3	1	7	5	5	3	7	9	3	-	7	3	4	2	7
	200 to 499	6	5	9	8	4	7	5	8	3	3	11	13	7	8	5	15	6	3	6	7	3	8	9	7	6	15	2	3	1	5	5	3
	500 to 999	9	5	2	2	7	3	1	2	5	3	2	2	9	5	1	2	4	3	3	2	9	4	2	-	3	3	-	-	-	2	-	-
	>1000	-	6	-	-	-	4	-	2	-	3	-	2	-	3	-	2	-	3	-	3	-	5	-	2	-	5	-	3	-	-	-	2
2	<50	-	3	5	10	1	5	3	7	1	2	4	3	3	8	3	5	1	4	5	5	1	3	3	3	6	2	3	3	4	5	5	3
	50 to 99	-	2	3	3	3	3	6	4	-	4	3	3	8	3	5	8	-	3	4	-	1	-	6	-	3	1	6	2	10	-	9	5
	100 to 199	1	3	-	1	1	3	-	3	-	-	-	2	7	2	-	8	2	3	-	3	2	3	1	3	1	5	2	2	6	2	2	3
	200 to 499	1	5	2	3	1	3	3	-	3	3	2	2	3	6	8	2	4	6	5	3	3	3	3	2	1	2	5	3	4	12	6	7
	500 to 999	3	-	1	1	-	-	-	-	-	-	-	-	3	2	2	-	4	3	-	-	1	2	1	2	4	2	-	-	5	4	3	-
	>1000	-	-	-	2	-	-	-	-	-	2	-	1	-	2	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	4	-	-
1	<50	3	2	3	1	1	2	2	-	-	2	-	-	1	5	3	-	-	-	4	-	-	-	2	-	-	5	6	5	3	2	8	2
	50 to 99	1	2	1	2	-	-	-	-	-	-	-	1	-	-	2	-	-	1	-	-	-	-	-	1	1	-	2	-	3	3	2	-
	100 to 199	-	-	-	3	-	-	1	-	-	-	-	1	-	-	-	-	1	-	-	-	1	-	-	-	1	-	-	-	4	5	2	3
	200 to 499	1	5	-	-	-	2	-	2	-	2	-	4	-	1	-	-	1	3	-	-	-	-	-	1	1	-	2	-	7	3	2	5
	500 to 999	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	3	-	-	6	2	-	-
	>1000	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	2	-	-	-	5	-	-

W - Wool; Co - Cotton; K - Knitting; Cl - Clothing
4 - Very important; 3 - Important; 2 - Less important; 1 - Not important

Table 59 - Means to improve quality

	No. of employees	Training				Process control				Equipment / technology				Engineers				Workers control				Suppliers control				Customer service			
		W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl
4	<50	3	10	12	11	4	6	5	10	3	2	8	5	1	-	3	2	3	6	-	-	3	5	-	3	2	8	7	8
	50 to 99	6	5	13	5	6	3	5	7	4	-	4	3	-	-	2	-	-	2	-	-	1	2	-	5	3	2	8	7
	100 to 199	4	5	5	10	3	6	6	8	4	1	4	5	1	2	-	5	-	-	2	2	-	3	5	7	2	4	5	5
	200 to 499	6	7	8	13	7	9	6	13	1	8	2	2	1	-	2	2	-	-	3	5	1	3	5	5	1	6	2	9
	500 to 999	6	3	-	-	4	5	3	2	3	3	-	-	-	-	-	-	-	-	2	-	-	-	-	2	-	-	2	2
	>1000	-	3	-	2	-	3	-	2	-	-	-	-	-	-	-	2	-	3	-	-	-	2	-	2	-	2	-	-
3	<50	3	2	3	5	3	4	9	5	4	7	6	7	3	3	2	-	1	4	11	5	5	5	3	7	4	5	9	8
	50 to 99	6	3	5	7	4	5	11	5	8	3	8	8	8	-	3	2	6	1	6	3	4	1	14	3	6	2	9	5
	100 to 199	5	1	2	5	6	5	3	5	7	5	3	8	7	-	-	-	5	-	3	2	7	2	2	2	5	4	-	7
	200 to 499	3	11	5	5	2	5	5	6	8	5	11	10	3	2	2	3	7	5	8	8	6	8	5	11	4	6	3	4
	500 to 999	3	5	3	-	7	3	-	-	8	3	3	-	3	-	-	-	9	3	-	-	2	4	1	1	6	3	-	1
	>1000	-	3	-	-	-	2	-	1	-	5	-	2	-	3	-	-	-	2	-	-	-	2	-	2	-	1	-	2
2	<50	3	-	3	2	3	6	4	2	3	3	5	4	6	6	5	7	3	6	5	8	1	6	13	5	3	2	2	-
	50 to 99	-	-	2	1	5	-	5	-	-	3	8	-	6	3	12	3	9	3	11	8	6	2	6	3	5	2	3	1
	100 to 199	3	4	2	1	3	-	-	3	2	3	2	2	4	3	4	5	4	6	4	7	3	3	2	7	5	2	2	3
	200 to 499	3	2	3	3	-	5	3	2	3	5	3	3	4	7	9	11	4	9	3	4	4	9	3	3	6	5	8	5
	500 to 999	3	-	-	2	1	-	-	-	1	2	-	-	6	3	2	2	3	3	1	2	9	2	2	-	6	3	-	-
	>1000	-	-	-	2	-	2	-	-	-	1	-	3	-	3	-	3	-	3	-	5	-	5	-	1	-	3	-	2
1	<50	1	6	3	-	-	2	3	1	-	6	2	2	-	9	11	9	3	2	5	5	1	2	5	3	1	3	3	2
	50 to 99	3	-	2	-	-	-	1	1	3	2	2	2	1	5	5	8	-	2	5	2	4	3	2	2	1	2	2	-
	100 to 199	1	1	-	2	1	-	-	2	-	2	-	3	1	6	5	8	4	5	-	7	3	3	-	2	1	1	2	3
	200 to 499	-	-	-	-	3	1	2	-	-	2	-	6	4	11	3	5	1	6	2	4	1	-	3	2	1	3	3	3
	500 to 999	-	-	-	-	-	-	-	-	-	-	-	2	3	5	1	-	-	2	-	-	1	2	-	-	-	2	1	-
	>1000	-	3	-	1	-	2	-	2	-	3	-	-	-	3	-	-	-	1	-	-	-	-	-	-	-	3	-	1

W - Wool; Co - Cotton; K - Knitting; Cl - Clothing
4 - Very important; 3 - Important; 2 - Less important; 1 - Not important

Table 60 - Importance of human resources for quality

	No. of employees	Top management				Middle management				Supervisors				Workers			
		W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl
1st	<50	3	11	13	10	7	6	7	7	7	8	13	10	4	9	11	8
	50 to 99	4	6	13	3	7	3	10	3	6	5	5	5	10	6	6	8
	100 to 199	7	8	6	10	6	6	2	7	4	4	3	8	4	7	2	8
	200 to 499	6	10	8	8	3	9	8	4	3	5	6	8	4	10	8	8
	500 to 999	3	2	2	1	4	2	2	-	7	-	3	-	2	2	3	2
	>1000	-	7	-	2	-	3	-	-	-	2	-	2	-	2	-	3
2nd	<50	-	-	-	1	-	3	8	3	3	6	3	2	4	3	2	3
	50 to 99	4	2	-	-	4	2	5	2	6	-	5	6	3	-	6	3
	100 to 199	2	1	-	-	6	1	2	2	5	4	2	4	3	-	4	5
	200 to 499	2	-	2	-	6	6	5	4	3	10	7	5	-	2	-	5
	500 to 999	2	3	1	-	4	2	1	1	1	2	-	1	3	2	-	-
	>1000	-	1	-	-	-	3	-	3	-	2	-	1	-	-	-	-
3rd	<50	1	2	3	-	3	3	3	3	-	2	3	6	1	6	3	-
	50 to 99	1	-	5	2	4	-	5	6	3	3	6	2	1	-	5	-
	100 to 199	1	-	-	-	-	4	3	6	3	3	2	3	4	-	1	-
	200 to 499	-	-	2	2	3	5	3	5	3	3	3	3	4	5	3	-
	500 to 999	-	-	-	-	4	4	-	1	4	3	-	1	1	2	-	-
	>1000	-	-	-	1	-	3	-	2	-	5	-	2	-	2	-	-
4th	<50	6	5	5	7	-	6	3	5	-	2	2	-	1	-	5	7
	50 to 99	6	-	4	8	1	3	2	2	-	-	6	-	1	2	5	2
	100 to 199	3	2	3	8	-	-	2	3	1	-	2	3	2	4	2	5
	200 to 499	4	10	4	11	-	-	-	8	3	2	-	5	4	3	5	8
	500 to 999	7	3	-	1	-	-	-	-	-	3	-	-	6	2	-	-
	>1000	-	1	-	2	-	-	-	-	-	-	-	-	-	5	-	2

W - Wool; Co - Cotton; K - Knitting; Cl - Clothing

Table 61 - Customer requirements by company size

No. of employees	Due date				Test equipment				Production technology and equipment				Quality assurance			
	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl
<50	10	15	14	13	3	5	3	-	3	2	3	2	8	11	14	11
50 to 99	15	8	21	13	3	2	6	-	3	2	6	-	13	5	19	11
100 to 199	10	11	9	16	1	3	8	3	1	2	5	2	6	11	8	15
200 to 499	12	19	16	18	1	-	5	2	1	-	2	5	12	19	16	11
500 to 999	12	6	2	3	5	2	-	2	1	-	-	-	9	8	3	3
>1000	-	8	-	5	-	5	-	3	-	3	-	2	-	6	-	5

Table 62 - Quality costs by sub-sector and company size

No. of employees	Q. costs are evaluated	Q. costs not evaluated	Estimations	Q. costs are evaluated	Q. costs not evaluated	Estimations
	Wool			Cotton		
<50	1 0.5% (1)	9	- (5) 3.5% (2) 5% (2)	6 - (1) 2.5% (1) 4.7% (1) 5% (3)	11	- (3) 1% (4) 3% (3) 3.5% (1)
50 to 99	6 - (3) 2.6% (1) 3% (2)	10	- (8) 5% (2)	1 5% (1)	6	- (4) 4% (2)
100 to 199	3 10% (1) 15% (2)	9	- (4) 1% (1) 5% (2) 10% (2)	8 - (2) .8% (1) 4% (2) 6% (3)	6	- (2) 1.5% (1) 5% (3)
200 to 499	3 - (1) 5% (1) 6% (1)	9	- (5) 1% (1) 3% (1) 5% (2)	8 .7% (1) 2.4% (1) 5% (3) 8% (3)	11	- (6) 5% (2) 6% (1) 10% (2)
500 to 999	4 - (2) 10% (1) 15% (1)	8	- (5) 1% (1) 5% (2)	6 5% (2) 7.5% (1) 10% (3)	3	- (1) 20% (2)
>1000	-	-	-	5 2% (2) 10% (3)	3	4% (1) 10% (2)
	Knitting			Clothing		
<50	8 3% (2) 5% (2) 6% (1) 10% (2) 30% (1)	13	- (3) 1% (2) 2% (2) 4% (2) 5% (4)	7 .5% (2) 2% (3) 4% (1) 6% (1)	11	- (3) 2% (3) 5% (3) 10% (2)
50 to 99	6 4% (2) 8% (1) 10% (2) 25% (1)	16	- (4) 5% (7) 10% (4) 12% (1)	5 3% (2) 5% (2) 15% (1)	8	- (3) 2% (1) 10% (4)
100 to 199	6 - (3) 3% (1) 5% (2)	3	- (2) 5% (1)	11 1% (1) 3% (2) 5% (3) 10% (4) 20% (1)	7	- (2) 2% (1) 5% (3) 15% (1)
200 to 499	7 - (2) 3.5% (1) 5% (3) 20% (1)	9	- (4) 4% (1) 10% (4)	5 1% (2) 1.9% (1) 10% (2)	14	- (4) 3% (3) 5% (5) 10% (2)
500 to 999	-	3	- (1) 10% (1) 20% (1)	2 3% (1) 5% (1)	2	10% (2)
>1000	-	-	-	2 1.2% (1) 5% (1)	3	- (2) 15% (1)

Table 63 - Specific training in quality by sub-sector and company size

No. of employees		Quality manager				Inspectors				Analysts				Others			
		W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl
<50	a)	-	2	2	3	-	7	-	3	-	-	-	-	-	2	-	-
	b)	3	2	-	2	1	-	-	-	2	-	-	-	2	-	-	-
	c)	-	3	-	-	2	2	-	-	-	-	-	-	-	-	-	-
50 to 99	a)	3	2	2	-	6	3	3	5	3	-	-	2	-	2	2	2
	b)	5	-	7	2	2	2	7	-	1	-	3	-	-	2	-	-
	c)	3	-	-	-	-	-	-	-	2	-	-	-	-	-	2	-
100 to 199	a)	-	2	2	9	2	5	3	12	2	-	-	-	5	3	-	-
	b)	3	5	2	2	1	-	2	-	-	-	-	-	-	-	-	-
	c)	-	2	-	2	-	-	-	2	-	-	-	-	-	-	-	2
200 to 499	a)	3	3	3	-	5	12	10	9	2	5	3	3	2	2	3	2
	b)	5	5	5	5	-	-	2	2	-	2	-	-	-	2	-	3
	c)	2	5	2	-	3	-	-	-	1	2	2	-	-	2	-	-
500 to 999	a)	2	-	-	-	3	5	2	-	1	-	2	-	3	3	2	-
	b)	1	3	2	-	3	2	2	-	-	2	-	-	-	-	-	-
	c)	3	-	-	2	2	-	-	2	5	-	-	-	-	-	-	2
>1000	a)	-	3	-	2	-	7		3	-	5	-	2	-	3	-	-
	b)	-	3	-	2	-	-		-	-	-	-	-	-	-	-	-
	c)	-	2	-	-	-	-		-	-	2	-	-	-	2	-	-
a) Internal training; b) External training; c) Internal and external training																	

Table 64 - Organisation for quality by sub-sector and company size

No. of employees	Quality Manual				Calibration of test equipment				Inspection of raw materials				Statistical techniques				Standardisation			
	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl
<50	1	3	2	1	6	11	5	7	10	13	16	16	-	5	3	-	5	8	8	8
50 to 99	1	-	-	-	6	3	6	5	9	6	19	12	3	-	2	3	4	2	9	3
100 to 199	5	3	-	2	7	8	3	8	8	11	9	16	4	5	2	7	6	6	2	5
200 to 499	3	8	3	-	7	13	8	7	11	18	16	18	3	6	8	5	5	15	9	5
500 to 999	6	2	-	-	12	7	2	-	12	8	3	-	8	3	2	-	8	3	2	2
>1000	-	5	-	2	-	8	-	3	-	8	-	5	-	8	-	2	-	8	-	2

Table 65 - Support to quality problems by sub-sector and company size

No. of employees	Suppliers				Customers				Other companies				Technical/ professional associations				Universities				Consultants				Other entities			
	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl	W	Co	K	Cl
<50	6	11	14	10	3	5	2	5	1	5	2	3	3	5	5	5	3	8	5	7	3	3	2	2	4	2	-	-
50 to 99	12	8	17	11	3	2	3	7	3	3	5	5	6	-	6	2	6	3	3	-	-	3	2	-	4	2	6	3
100 to 199	4	6	6	13	1	2	-	7	-	2	-	2	8	6	2	7	6	10	5	5	3	6	2	2	1	3	2	2
200 to 499	8	13	11	15	1	2	3	15	-	5	-	-	6	10	6	5	4	13	14	3	3	8	3	5	4	3	6	3
500 to 999	12	6	2	-	3	2	-	2	-	-	2	-	3	5	2	-	8	3	3	2	3	-	-	2	4	3	-	-
>1000	-	5	-	5	-	5	-	-	-	-	-	-	-	3	-	2	-	6	-	-	-	3	-	5	-	-	-	-